DECOMMISSIONING OF

THE SOUTH BAY MINE

USING

ECOLOGICAL ENGINEERING

1994 FINAL REPORT

By

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December 20, 1994

EXECUTIVE SUMMARY

The water quality data for Confederation Lake do not suggest a deterioration. Although the discharge from Boomerang Lake at station C1 was high during spring run-off in 1994, by the end of the year, the concentrations were similar to those reported for 1992. This reduction can be potentially accounted for by the phosphate rock application carried out in 1993 and 1994 in Boomerang Lake. Further applications of fine ground phosphate rock are planned for 1995 to counteract the slow, but steady, acidification of Boomerang Lake.

The Backfill Raise Diversion Ditch has reduced the contaminant loading to Confederation Lake from the surface seepages significantly. The bottom water at station C8 shows higher concentrations of zinc than the surface water. Electromagnetic surveys have established that a seepage enters Confederation Lake at a depth of about 6 m at the Mill site. The effects of the diversion ditch, in terms of stopping the deep seepage discharge, are more difficult to quantify. A slower response by the groundwater flow regime to hydrogeological modifications can be anticipated, compared to more rapid surface water seepage responses. Monitoring will continue in 1995 and remedial actions will be developed.

The hydrological reevaluation of the perched tailings area carried out in 1993 leads to the conclusion that, with changes in the geochemical and hydrological conditions in the tailings, permeability and flows leaving the tailings area can change correspondingly. It was suspected that Mud Lake water quality may be deteriorating. This indeed was the case, and the investigations carried out in 1994 have been documented in a separate report which has been submitted to the Ministry *of* Environment and Energy in December 1994. In the Mud Lake Report, detailed recommendations are made for a full hydrological assessment of the entire site in 1995.

The deterioration of Decant Pond water quality, due to acid discharge from the tailings beach (noted in 1992), has been successfully counteracted through the installation of an ARUM (Acid Reduction Using Microbiology) berm along the beach. Treatment of the acid pool on the tailings with phosphate rock has reduced the iron and aluminum loadings to the pond. Zinc concentrations in the discharge from Decant Pond have been around 1 mg/L in 1994, as compared to 9 mg/L by the end of 1992.

The biological polishing process, its capacity to remove zinc, along with detailed evaluations of iron cycling, sediment chemistry and the work carried out on the phosphate rock applications in Boomerang Lake, have been summarized in a report entitled: Biological Polishing Phase IV: Model Verification and Scale-up (CANMET Contract, July 1994). This report has also been submitted to the Ministry of Environment and Energy, and describes part of the ongoing research for the decommissioning of the South Bay mine site.

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1.0 INTRODUCTION

In April, 1993, a report was submitted to the Ministry of the Environment entitled "Decommissioning of South Bay Mine Using Ecological Engineering", summarizing the field and laboratory work carried out to date covering 1991 and 1992. In addition to the regular monitoring activity, recommendations were made in this report which defined the 1993/1994 program objectives. Those were as follows:

Mine/Mill Site: An evaluation of the Backfill Raise Diversion Ditch, in terms of its effectiveness in diverting seepages away from Confederation Lake, was recommended. This ditch was designed to collect seepage from the mill/mine site and direct it to Boomerang Lake. The benefits of modifications, including ditch bank stabilization or ditch deepening, were to be assessed.

Decant Pond: The effectiveness of the placement of organic matter on the tailings beach and the placement of the phosphate rock in the upper part of the tailings seepage area were to be monitored. A re-assessment of the tailings hydrology was to be carried out.

Boomerang Lake: In Boomerang Lake, the residual acidity which has been accumulating since 1981 was to be addressed through additions of phosphate rock. The applications were to be carried out based on the field and laboratory results. The application of phosphate rock to lake sediments was to be assessed during the winter and spring run-off.

Section 2 of this report summarizes the monitoring data for the regular sampling stations. The performance of the Backfill Raise diversion ditch and the remedial measures for the mill/mine site area are summarized in Section 3. The results of the evaluation of the hydrology of the tailings and the performance of the ARUM berm at Decant Pond beach, along with the phosphate rock placed in the tailings run-off, are discussed in Section 4. Finally, the Boomerang Lake long-term water quality trends and contaminant loadings, the most complex aspects of the site, are discussed in Section 5.

A model has been developed in the past yews to quantify the biological polishing process. Jointly funded research efforts addressed details of the phosphate rock applications to sediments and the role of iron cycling in Boomerang Lake. A report entitled "Biological Polishing: Phase IV Model Verification and Scale-up" (July, 1994) summarizes the effects *of* the phosphate rock applications and the expected biological polishing performance in Boomerang Lake. This report has been submitted to the Ministry of Environment and Energy, and the findings will not be included in this report.

1.1 Project Background

The South Bay Mine, a copper/zinc operation active between 1971 and 1981, generated 0.75 million tonnes of tailings with a pyrite content of 41 % and a pyrrhotite content of 4 %. The site is located 85 km northeast of Ear Falls in northwestern Ontario. Acid generation, based on the sulphur content *of* the tailings, is expected to continue for a minimum of 1,000 years and a maximum of 36,000 years.

To control the environmental degradation which results from acid generation, lime treatment is generally used. At this site, similar to all mining waste management areas with pyritic wastes, treatment would be required in perpetuity. Potentially, several treatment facilities are required to treat seepages from different sources, such as underground workings, waste rock and tailings piles. The treatment facilities would require maintenance, and sludge accumulated from the treatment process would have to be disposed of. Alternatives to this environmentally and economically unattractive lime treatment have been sought over the past 10 years.

BP Resources commissioned Boojum Research Limited in 1986 to assess the feasibility of developing the Ecological Engineering approach for the decommissioning *of* the site. At that time, Ecological Engineering in the mineral sector was only developed at a conceptual level. It is based on ecological principles of ecosystem recovery and draws on available measures to reconstruct ecosystems within the waste management area. These ecosystems, which are proposed to be developed inside the acidified lake (Boomerang Lake) and in the former Decant Pond on the tailings, are expected to provide conditions, once they are established, which would transfer the annual contaminant loadings from water to sediments.

Two natural contaminant removal processes used in Ecological Engineering are Biological Polishing for zinc and iron, and ARUM (Acid Reduction Using Microbiology) for metal precipitation in the sediments of polishing ponds. They are generally used together in the waste management areas or in a sequence determined by the waste water chemistry.

In Biological Polishing, attached algae grow on brush where they adsorb, co-precipitate and sequester metals to the biomass. This biomass settles and becomes part of the sediment. ARUM is a sediment-bound process which will remove sulphate and generate alkalinity through microbial iron and sulphate reduction. Stimulation of microbial activity in the sediment is achieved through additions of easily degradable carbon which enhances anaerobic conditions required for metal precipitation. The algal biomass from the biological polishing system is expected, in the long term, to replace the carbon additions to the sediment. The phosphate rock additions to the sediment creates a phosphate nutrient pool for support of the developing ecosystem in the waste management areas, such as Decant Pond and Boomerang Lake.

As the research progressed on each of the processes, measures were emplaced in stages to develop the ecosystem. Biological polishing capacity was increased annually by adding brush cuttings to Boomerang Lake, thereby increasing the surface area available for algal growth. In Decant Pond, inert demolition materials from the mine/mill buildings were used to provide surface area for algal growth. Decant Pond receives intermittent seepage from the tailings and might have slowly acidified. To counteract this acidification, the seepage from the tailings beach is forced through an organic matter berm constructed with 40 truck loads of wood waste placed in 1992. Laboratory tests with the material determined that the material was suitable to stimulate microbial activity (ARUM).

The overall objective of all processes and measures implemented is to contain the contaminants within the waste management areas in order to prevent deterioration of Confederation Lake water quality. The primary groundwater flow paths, from the tailings and the mine/mill site to Confederation Lake, were identified through hydrological studies. Groundwater plumes and seepage paths were intercepted with diversion ditches designed to direct the seepage towards Boomerang Lake. Groundwater was intercepted between the tailings and the town site in 1988, and a diversion ditch was created from the mine/mill site to Boomerang Lake in 1992. Boomerang Lake has been designated as the main polishing pond or treatment area for water from the mine site and the southern and western groundwater plumes from the tailings.

Between 1991 and 1993, much of the research effort for the site has been to determine the treatment capacity of the processes which are to be scaled up in Boomerang Lake and implemented in Decant Pond. This requires an reasonably reliable estimate of the annual contaminant loadings to Boomerang Lake and the contaminant removal rates which can be expected from the treatment processes. The first round of calculations of total loadings from the site to Boomerang Lake, compared to contaminant removal capacity, suggest that the biological systems can remove the annual loadings.

However, estimates of the capacity of the polishing system vary widely. They depend on the type of growth rates used (exponential or linear) and on the uptake/ adsorption/ precipitation rates of contaminants. A combination of field and laboratory experiments were used to derive the relevant parameters to quantify the metal removal process which is mwiated by the algae. Increased algal growth rates upon addition of nutrients was achieved in both laboratory and field trials.

Increasing nutrient concentrations in acidic water is difficult due to the chemistry of both phosphorus and nitrogen at low pH. Ammonia, the major form of nitrogen present, is not the most widely utilized form of nitrogen used by biota, while phosphate will precipitate with metals and is subsequently bound in the sediment. A sedimentary phosphate rock (Texasgulf), mined and sold worldwide as a fertilizer for acidic soils, might be a suitable material to increase phosphate in Boomerang Lake water and sediment. This sedimentary phosphate rock, when it dissolves in acidic conditions, consumes acidity and precipitates metals. Thus, upon determining the appropriate applications rate, phosphate which has not be precipitated or relegated to the sediment will serve as a nutrient to those algal populations serving as biological polishing agents.

The biologically-driven passive treatment processes can only address annual contaminant loadings, while it does not appear possible to remove the residual contaminants generated in the past and accumulated in the system. In 1992, work addressing the residual contaminant loading in Boomerang Lake, Mill Pond and Decant Pond was initiated with the application of about 6 tonnes of phosphate rock distributed in the various water bodies. The results were promising, particularly trials using a fine-grained phosphate rock. The fine-grained material supplied by Texasgulf for the first trials could not be bagged in the quantities required. The next best performing material was substituted and 100 t of the material was proposed to be added to the sediments of Boomerang Lake. Due to logistical problems, only 50 tonnes were distributed in the lake in 1993, the remainder being placed in the summer of 1994.

The correct formulation of phosphate rock, applied appropriately, will not only serve as a nutrient source but could also assist in fixing those metals accumulated in the system. Given its chemical characteristics, phosphate rock can be utilized for removal of residual contaminants from Boomerang Lake. This would create more appropriate conditions for the passive treatment system to deal with the annual loadings from the tailings site and the mill site. Arrangements are being made to apply the appropriate quantity, using a barge which can handle 1 tonne bags, of the tine-grained phosphate rock to Boomerang Lake in the spring of 1995.

2.0 MONITORING DATA FOR REGULATORY SAMPLING LOCATIONS

The overall objective of Ecological Engineering measures being implemented at the South Bay site is to retain contaminants within the waste management area and Boomerang Lake. Four sampling stations are regularly monitored at locations around the waste management area of the South Bay site in order to assure that the water quality of Confederation Lake is not deteriorating while the decommissioning approach is being developed and implemented in stages over the years. The locations of the four stations, **C1,** C8, **C11** and **M54** are shown on Map **1,** and the monitoring data for each of the four stations for the period of October **1986** to June **1994** are summarized in Tables **1** to **4.**

2.1 Station C1 - Lost Bay Near Boomerang Lake Outflow

Sampling Station **C1** is located 3 m away beyond the point where Boomerang Lake discharges water into Lost Bay, a section of Confederation Lake (Map **1).** Since the depth of the water in this area is less than **0.4** m, a grab sample is always collected at this site. Generally, the metal concentrations at this site are at the same "elevated levels" as those in Boomerang Lake during the spring run-off, and then subside to acceptable levels during the summer months (Table 1). **Also,** during the spring run-off the pH decreases somewhat, while the sulphate concentrations increase.

Between May **16, 1991** and March **24, 1992,** water samples werwcollected right at the mouth of the channel draining Boomerang Lake into Lost Bay instead of the normal location 3 m from the mouth. **As** a result, these samples represent Boomerang Lake water prior to any mixing with Lost Bay water. Zinc concentrations in these samples were consistently higher (6 to **8.4** mg/L) than those previously measured at the regular **C1** sampling station. In addition, the pH was lower, ranging from 3.3 to **4.1,** and the sulphate concentrations were elevated at > **219** mg/L.

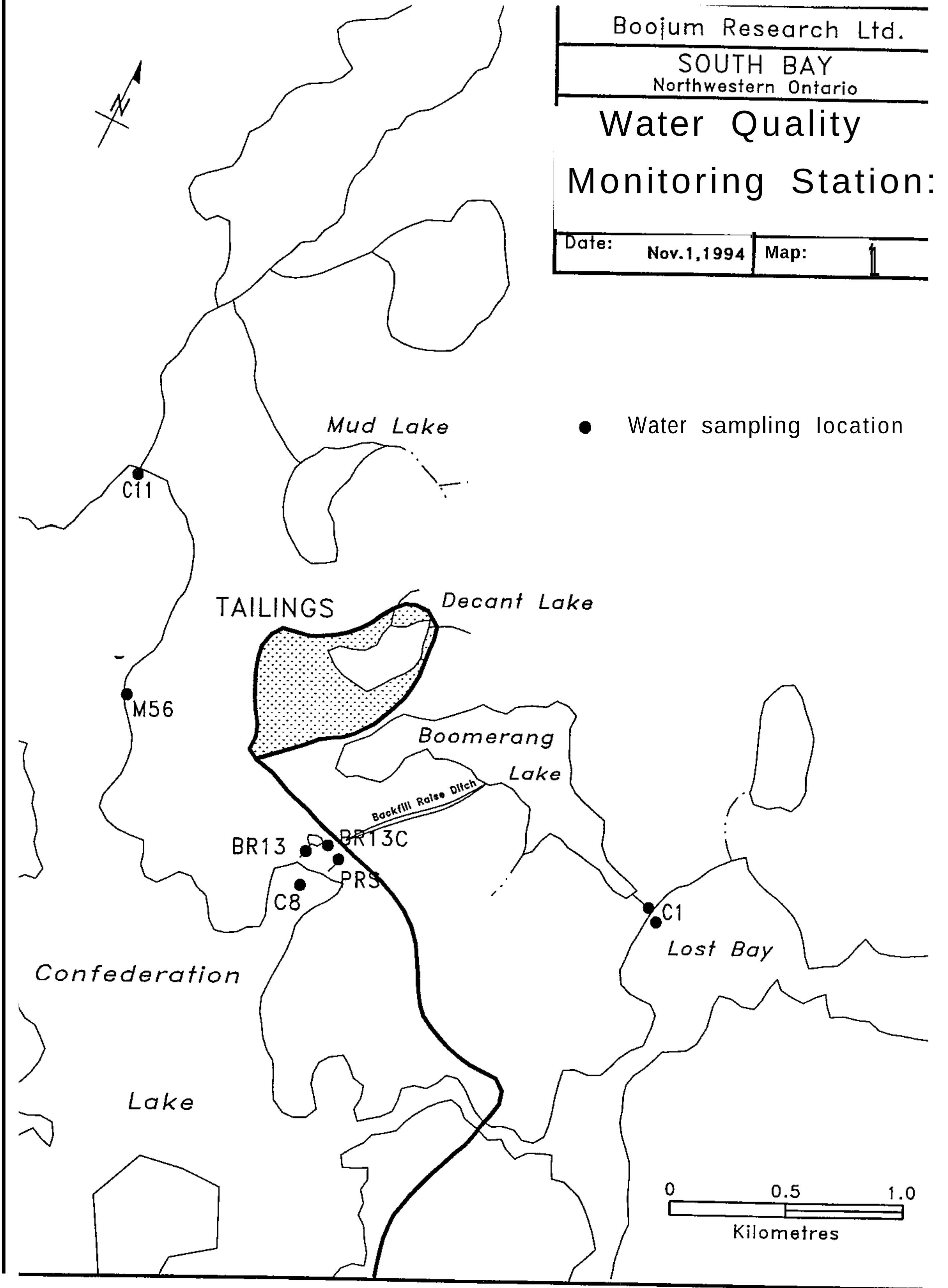

Boojum Research Ltd.
SOUTH BAY
Northwestern Ontario
Water Quality
Monitoring Station:
Date:
Nov.1,1994
Map:
1
N
Mud Lake
Water sampling location
C11
TAILINGS
Decant Lake
M56
Boomerang
Lake
Backfill Raise Ditch
BR13
BR13C
PRS
C8
C1
Lost Bay
Confederation
Lake
0
0.5
1.0
Kilometres

Table 1: Chemistry of sampling location C1, Confederation Lake

Sample Date	pH	Acidity mg/L as CaCO3	SO4 mg/L	Zn mg/L
15-Oct-86	6.30	nd	11.70	1.70
05-Apr-87	6.05	nd	180.00	6.50
27-Apr-87	6.20	nd	13.80	0.16
31-May-87	6.64	nd	24.00	0.60
12-Apr-88	5.85	nd	66.00	< 0.01
24-May-88	6.93	nd	23.40	0.40
23-Jun-88	7.46	nd	10.80	0.05
25-Aug-88	6.39	nd	3.30	0.01
14-May-89	4.59	nd	204.00	6.10
25-Aug-89	6.70	neg	63.00	1.80
25-Aug-89	6.70	43.0	174.00	0.09
03-Jun-90 *			4.50	< 0.01
23-Jun-90	6.30	26.0	29.10	0.70
11-Oct-90	6.63	20.0	6.30	0.30
16-May-91 @	3.26	50.0	251.40	8.38
25-Jun-91 @	3.69	78.0	237.90	6.25
26-Jul-91 @	3.57	100.0	219.00	6.00
28-Sep-91 @	3.47	40.0	258.00	6.57
24-Mar-92 @	4.07	40.0	243.00	7.00
14-Jul-92	6.06	6.5	59.10	1.42
18-Jul-92	6.36	15.0	41.40	1.18
17-Oct-92	6.40	3.3	** 7.10	0.12
08-Apr-93	4.73	4.5	77.10	1.27
17-Jun-93	6.58	4.0	34.20	0.67
11-Sep-93	6.38	4.9	41.70	1.90
10-Oct-93	6.37	2.0	6.54	0.10
30-Mar-94	5.48	58.9	175.00	5.82
26-Apr-94	3.98	36.7	105.30	4.52
18-Jun-94	5.87	25.9	70.20	2.43
14-Jul-94	not sampled			
30-Aug-94	6.9	16.1	28.02	1.21

@- change of sampling location

neg - negligible acidity

• - acidified on site, collected by Milt Ramsden

nd - not determined

** - determined by Boojum

Between July 14, 1992 and October 10, 1993, water sampling collection returned to the original location in Lost Bay, 3 m from the mouth of Boomerang Lake. During this period, the measured zinc concentrations were no higher than 1.9 mg/L, and as low as 0.1 mg/L on 2 of the 7 sampling occasions. Similarly, sulphate concentrations were 78 mg/L or less. The pH was higher than 6.1 on *6* of the 7 occasions, with a lower value of 4.7 during the April 8, 1993 sampling.

During 1994, the winter (March 30) and spring run-off (April 26) samples from station C1 contained 5.8 and 4.5 mg/L zinc, respectively. In comparison to results from samples collected during the ice free season, these are relatively high concentrations. However, by June 19, the zinc concentration had decreased to 2.4 mg/L, and on August 30, was only 1.2 mg/L.

In early 1991, it was recognized that the zinc concentrations that were being discharged from Boomerang Lake into Lost Bay were highly undesirable. The higher zinc levels in Boomerang Lake were not unexpected. Concentrations were anticipated to increase as a result of additional zinc input from waters draining underground workings and discharging into the lake following the construction of the Backfill Raise Diversion Ditch in 1992. However, zinc concentrations rose to levels higher than were expected. Thus, in 1993 and 1994, remedial measures, in the form of phosphate rock addition, were implemented.

As previously mentioned, a seasonal reduction from 5.8 to 1.2 mg/L in zinc concentrations discharging into Lost Bay was observed to occur in 1994. Although part of this reduction is anticipated to have resulted from the addition of phosphate rock, the actual effects of phosphate rock addition may be slow to determine. Some of the zinc reduction may be the result of adsorption by the algal bloom that was noted to have developed in the lake by the end of the summer.

2.2 Station C8 - Confederation Lake Near Mill Area

Sampling station C8 is located in the centre of a small bay of Confederation Lake adjacent to the Mill site (Map 1). The maximum depth of water in this bay is 6 m. Grab samples are taken 30 cm below the surface at this location. Temperature profiles measured on July 13,1992, June 16,1993, September 12,1993 and October 10,1993 indicate that there is no more than a 2°C difference between surface and bottom waters. The narrow range of temperatures suggests that during the ice-free season, the water column probably mixes, and as a result, a grab sample at a depth of 30 cm is thought to be representative of the bay.

Station C8 has been regularly sampled since October 15, 1986. During this period, zinc concentrations have remained at or below 0.83 mg/L, and the pH has remained at or above 5.5 (Table 2). Measured sulphate concentrations have never exceeded 42 mg/L, and acidity has never exceeded 20 mg/L *of* $CaCO_3$ equivalent.

Sampling results from between May 15, 1991 and June 17, 1993, indicate that zinc, sulphate and acidity concentrations were increasing slightly during this period. Zinc concentrations were above 0.1 mg/L on 10 out of 11 sampling occasions, and above 0.2 mg/L on 8 of those occasions.

This period of slightly elevated zinc concentrations was likely related to additional zinc input asw result of higher run-off from the Mill site because of exceptionally high rainfalls encountered in 1991 and 1992. In response to these higher zinc levels, the Backfill Raise Drainage Ditch was deepened in the fall of 1992 to lower the groundwater level in the Mill area with the objective that this would in turn eliminate drainage from the Mill area into Confederation Lake.

Table 2: Chemistry of sampling location C8, Mill *Site* Bay

Sample Date		pH	Acidity mg/L as CaCO3	SO4 mg/L	Zn mg/L
15-Oct-86		6.90	nd	5.10	0.13
05-Apr-87		7.07	nd	5.10	0.40
27-Apr-87		6.60	nd	8.10	0.09
31-May-87		6.45	nd	6.00	0.01
12-Apr-88		6.55	nd	10.80	< 0.01
24-May-88		7.22	nd	9.00	0.05
23-Jun-88		6.87	nd	7.80	0.04
25-Aug-88		6.16	nd	6.00	0.05
14-May-89		6.50	nd	9.30	0.20
25-Aug-89		6.80	nd	42.00	0.80
16-Oct-89		5.50	nd	10.20	0.01
03-Jun-90	*			3.60	< 0.01
23-Jun-90		6.60	neg	6.30	0.01
16-Apr-91		7.39	6.0	3.00	0.07
15-May-91		5.98	10.0	8.58	0.22
26-Jul-91		6.04	17.0	6.00	0.30
25-Sep-91		7.28	neg	21.00	0.45
24-Mar-92		5.94	20.0	9.00	0.11
14-Jul-92		6.46	1.8	9.36	0.08
17-Jul-92		7.69	5.0	13.89	0.20
14-Aug-92		7.25	2.0	6.66	0.21
14-Aug-92		6.79	2.5	11.88	0.83
17-Oct-92		6.33	4.2	** 3.80	0.29
14-Apr-93		7.05	2.3	< 5.90	0.16
17-Jun-93		6.01	1.9	8.40	0.27
12-Sep-93	s	7.29	1.5	7.98	0.07
12-Sep-93	b	7.09	4.2	8.22	0.56
10-Oct-93	s	6.98	2.0	7.17	0.07
10-Oct-93	b	7.00	3.0	7.44	0.09
28-Mar-94	s	6.76	2.3	13.23	0.21
28-Mar-94	b	7.07	2.9	41.10	0.95
26-Apr-94	s	6.69	2.6	4.50	0.09
26-Apr-94	b	6.65	4.0	8.10	0.13
18-Jun-94	s	6.68	2.2	8.16	0.08
18-Jun-94	b	7.01	nd	8.04	0.12
14-Jul-94		not sampled			
30-Aug-94	s	6.66	neg	7.71	0.077
30-Aug-94	b	6.71	neg	6.99	0.61

neg- negligible acidity
* - acidified on site, collected by Milt Ramsden
nd - not determined
** - determined by Boojum
s - surface
b - bottom

It is important to note that since June 17, 1993, surface water zinc concentrations at station C8 were less than 0.1 mglL on 5 out of 6 occasions. Bottom water samples were no more than 0.95 mg/L on all 6 of these occasions. These results strongly suggest that by deepening the Backfill Raise Drainage Ditch, most of the zinc loading from the Mill area may have been eliminated.

Two sampling locations, Portal Raise Seepage (PRS) and Backfill Raise 13 and 13C (BR13, BR13C) have been added to the monitoring station list (Table 3). These stations will be discontinued once the remedial measure have been proven to be effective.

2.3 Station C11 - Confederation Lake Near the Mud Lake Outflow

Since October 15, 1986, samples have been regularly collected at station C11, located 3 m from the point where Mud Lake discharge water joins Confederation Lake (Map 1). Up to March 24, 1992, zinc concentrations have never exceeded 0.35 mg/L, and on 13 out of 16 occasions, were lower than 0.1 mglL (Table 4). The pH during this same sampling period remained higher than 5.7. Sulphate was consistently lower than 39 mg/L, and acidity has never exceeded 41 mglL $CaCO_3$ equivalent.

Since July 14, 1992, and until the latest sample taken on August 30, 1994, zinc concentrations have been consistently higher than during the earlier period of monitoring.

Although zinc concentrations have exceeded 0.1 mglL on 9 out of 11 occasions, only one sample exceeded 1.0 mg/L, reaching 1.1 mglL on June 14, 19w. In 1993 the hydrology of the tailings basin was reevaluated because it was suspected that contamination was escaping from the mine site through the Mud Lake drainage basin. The contamination route through Mud Lake was confirmed in 1994.

Table **3:** Chemistry of sampling locations BR-13, BR-13C, & PRS, seepages

Sample Date	pH	Acidity mg/L as CaCO3	SO4 mg/L	Zn mg/L
BR-13				
25-Jun-91	3.00	556.0	2067.00	295.00
26-Jul-91	3.14	567.0	1386.00	199.00
25-Sep-91	3.72	600.0	1488.00	221.00
13-Jul-92	3.63	201.5	1092.00	173.00
16-Jul-92	5.54	172.5	507.00	84.20
14-Aug-92	3.61	505.0	1188.00	163.00
16-Oct-92	4.90	345.0		117.00
11-Apr-93	6.00	26.4		19.20
27-Apr-94	6.36	10.3	22.02	1.76
14-Jun-94	dry - no sample			
11-Jul-94	dry - no sample			
30-Aug-94	6.12	55.1	351	24.9
BR-13C				
14-May-89	5.60		3774.00	881.00
16-Jun-93	6.09	48.2		
07-Sep-93	6.56	33.9	290.40	12.80
14-Jun-94	5.74	53.8	298.2	13.5
11-Jul-94	not sampled			
PRS				
13-Jul-92	5.62	53.0	459.00	46.20
16-Jul-92	3.51	264.0	525.00	122.00
14-Aug-92	5.64	49.0	299.10	22.20
16-Oct-92	5.99	44.2		23.20
11-Apr-93	5.79	81.7		19.20
16-Jun-93	5.83	44.2		
07-Sep-93	5.56	292.8	936.00	137.00
09-Oct-93	5.66	419.0	1047.00	176.00
26-Apr-94	5.06	399.9	1071.00	186.00
18-Jun-94	5.38	58.3	648.00	89.00
11-Jul-94	4.38	409.8	1167.00	180.00
30-Aug-94	4.29	246.3	567	76.2

Table **4: Chemistry** of sampling location **C11, Mud** Lake **Outflow**

Sample Date	pH	Acidity mg/L as CaCO3	SO4 mg/L	Zn mg/L
15-Oct-86	6.60	nd	2.5	0.33
05-Apr-87	6.75	nd	6.8	0.03
27-Apr-87	6.60	nd	2.5	< 0.01
31-May-87	6.55	nd	12.0	< 0.01
12-May-88	7.15	nd	13.0	0.04
23-Jun-88	6.92	nd	8.1	< 0.01
25-Aug-88	6.01	nd	12.0	0.01
14-May-89	6.26	nd	12.0	0.03
25-Aug-89	6.62	nd	11.0	0.30
03-Jun-90 *			1.3	< 0.01
23-Jun-90	6.32	41	14.0	0.01
11-Oct-90	5.75	30	3.3	0.05
16-Apr-91	7.40	3	0.7	0.06
15-May-91	6.12	20	23.8	0.35
28-Sep-91	6.61	10	5.0	0.04
24-Mar-92	5.76	30	39.0	0.07
14-Jul-92	7.97	5.5	77.7	0.70
17-Oct-92	6.18	4.7	** 30.4	0.31
10-Apr-93	6.29	7.9	20.6	0.17
17-Jun-93	6.22	2.8	35.7	0.27
11-Sep-93	6.92	1.2	16.0	0.43
10-Oct-93	6.43	6.0	7.9	0.27
30-Mar-94	6.11	16.5	24.2	0.11
26-Apr-94	6.92	6.6	12.8	0.15
18-Jun-94	7.16	2.2	85.5	0.10
14-Jul-94	5.73	14.4	106.2	1.11
30-Aug-94	5.99	4.1	8.0	0.062

neg- negligible acidity
* - acidified on site, collected by Milt Ramsden
nd - not determined
** - determined by Boojum

2.4 Station M56 Piezometer - Confederation Lake Shore Near Town Site

The water quality in Piezometer M56 has been monitored closely, because its position is located on the shore of Confederation Lake, designed to intersect and sample groundwater that may have flowed in a direction from the tailings to the lake. Since monitoring began in 1989, the pH has always been between 6 and 7.8, while sulphate and acidity concentrations have remained low, at 38 mg/L sulphate and 25 mg/L $CaCO_3$ equivalent or below (Table 5).

While zinc concentrations have generally remained low in this piezometer, the first recorded occurrence of high levels was on October 17, 1992, when a zinc concentration of 1.16 mg/L was recorded. In the five samples collected in the period following this date, and including March 30, 1994, zinc concentrations dropped to, or were below, 0.13 mg/L. However, on June 14, 1994, a zinc concentration of 1.42 mg/L was measured, but by the next sampling date, August 30, 1994, had decreased to 0.03 mg/L.

Such a wide variation in zinc concentrations is not expected. A zinc-contaminated sampler (failure to pre-rinse) used in the collection of the two anomalous water samples could explain the high zinc concentrations. Presently, there is no other evidence indicating that groundwater with elevated zinc has migrated to the shore of Confederation Lake in the vicinity of M56.

Nevertheless, due to the anomaly in M56, the drainage basin was carefully assessed in 1994. A surface seepage pool was noted close to the tailings in the drainage path leading to M56. Piezometer M28 was sampled during 1994 to ascertain whether a groundwater plume is developing in this direction. The zinc concentrations were 0.1 mg/L as compared to the concentrations in the pool of 416 mg/L (M5 Seep station). The clean groundwater quality at M28 also suggests that anomalous zinc concentrations in M56 water were likely due to contaminated sampling equipment.

Table 5: Chemistry of piezometer M56

Sample Date	pH	Acidity mg/L as CaCO3	SO4 mg/L	Zn mg/L
25-Aug-89	6.88	nd	7.30	0.10
14-Oct-89 *	6.50	nd	3.00	0.04
14-Oct-89	6.25	nd	2.70	0.10
23-Jun-90	6.51	nd	1.20	< 0.01
11-Oct-90	6.02	nd	3.40	0.40
16-Apr-91	7.55	4.0	0.50	0.02
12-May-91	5.97	20.0	11.60	0.25
15-May-91 *	6.11	10.0	2.18	0.31
15-May-91	6.30	10.0	3.02	0.53
28-Sep-91	7.10	10.0	2.00	0.15
24-Mar-92	6.35	25.0	18.00	0.04
14-Jul-92	7.83	10.0	5.46	0.28
17-Oct-92	6.86	8.2	** 0.40	1.16
10-Apr-93	7.36	2.4	6.00	< 0.01
17-Jun-93	6.75	8.2	7.70	0.13
11-Sep-93	6.37	3.0	6.36	0.06
10-Oct-93	6.79	17.0	7.86	0.12
30-Mar-94 *	6.75	5.4	7.29	0.13
26-Apr-94	not sampled			
14-Jun-94	7.20	4.8	38.40	1.42
14-Jul-94	not sampled			
30-Aug-94	6.66	8.3	4.38	0.034

* - sampled at Confederation Lake Shore. surface sample near M56

nd - not determined

** - determined by Boojum

3.0 MILL SITE SEEPAGE SURVEYS

To determine the direction of groundwater flow, several piezometers were installed on the site in 1987 and have been monitored periodically over the years since. Relatively uncontaminated groundwater is flowing towards Confederation Lake, while contaminated groundwater flows toward Boomerang Lake.

Precipitation was unusually high in **1992,** resulting in a high groundwater table. Seepages developed from the mine site began flowing towards Confederation Lake. These seepages were sampled for chemical analysis, and these water quality data were used in geochemical simulations to determine the composition and origin of the seepages. The results of the geochemical modelling, presented in the 1992 **report,** indicated that the seepages were a combination of groundwater and surface run-off moving through waste materials.

Modelling results suggested that the Portal Raise Seepage (PRS, Map 1) water could be derived from a mixture of about 14% contaminated water with a composition similar to the Warehouse Seep (WHS), and 86% of uncontaminated groundwater. The characteristics of the Backfill Raise seepage (BR-13) could be derived as a mixture of some 43% of BRC water and 57% uncontaminated groundwater.

These proportions suggested that diverting the uncontaminated water would not only change the composition of the seepage waters, but also prevent uncontaminated water from being contaminated as it flows through the waste rock material on the mill site. Seepages were already evident in the sediment in a small bay of Confederation Lake close to the mill site. Bottom water samples have been collected since September 1993 at this site (Sampling Station C8) to monitor the effects of this seepage.

To reroute uncontaminated water from the mine site to Boomerang Lake, a diversion ditch was constructed in 1992. The design of the ditch included a bottom elevation low enough to intercept flows from the underground mine workings.

In addition to constructing the diversion ditch, an electromagnetic (EM) survey was carried out to investigate the nature of the groundwater. Groundwater quality has traditionally been assessed by the installation and sampling of piezometers, and the hydrology of the area is derived from interpolated between data points obtained from these piezometers. However, in recent years, EM techniques have been used as a means of delineating contaminant plumes associated with acid mine drainage. In addition, estimates of the depth of contaminated groundwater can often be calculated, thereby permitting linkage of the seepages to the underground workings.

Unfortunately, not all anomalies identified in EM surveys are the result of contaminated groundwater plumes. Other sources of anomalies in the area of mine sites may be massive sulphide-bearing rocks, various forms of scrap metal, buried or above ground cables, and buried concentrate. Thus, the indiscriminate use of EM surveys over old mine sites can lead to numerous misinterpretations. Given that a detailed knowledge of the decommissioning activities for South Bay was available to the contractor, it was possible to separate the anomalies suspected of having a contaminated groundwater source from those resulting from other mining activities. Anomalies selected as possibly representing contaminated groundwater were tested and confirmed through direct measurements. Although the results of ground truthing the EM survey for the South Bay Mill site have been summarized in Kalin and Pawlowski, **1994,** the purpose of presenting the results of the EM survey is to ascertain the depth of the seepages from the Mill site to Confederation Lake.

3.1 Methods

3.1.1 Electromasnetic Surveys and Electrical Conductivitv Surveys

Geophysical Surveys were carried out in March, 1992 and September 1993 in the Mill area, the bay of Confederation Lake adjacent to the Mill area, the tailings dam area along Boomerang Lake and the townsite. The objective of these surveys was to detect the location of contaminants and abandoned structures which could be relevant to underground seepage flow.

Fixed Frequency Electromagnetic (EM) Profiling techniques were employed using Geonics EM31-DL, EM31 and EM34-3 terrain conductivity meters. The measurements with EM31-DL were taken with vertically-oriented magnetic dipoles at hip level. The instrument in this configuration has a depth of penetration up to 6 m. The distance between the measurement points along the survey lines varied from 1 to 2 m. The EM34-3 instrument with a 10 m intercoil spacing gives an exploration depth of 0 to 7.5 m with horizontal dipoles and 15 m with vertical dipoles. With an intercoil spacing of 20 m, the exploration depth is 15 m with horizontal dipoles and 30 m with vertical dipoles. The relative contribution from material at different depths to the conductivity indicated by the instrument meter is discussed in detail by McNeill (1980, 1987).

The measurements with EM34-3 were taken at a distance of 10 m along survey lines. The intercoil spacing for the horizontal dipole mode was 10 and 20 m, while for the vertical mode it was 20 m. The survey was carried out by a two man crew. In the summer of 1993, the survey lines on the mine site were remeasured using EM31 only.

In the EM method, eddy current flow is induced in the ground by a time-varying magnetic field of a vertical or horizontal magnetic transmitter dipole operating at a fixed frequency. This eddy current flow induces a secondary magnetic field which, together with the primary field, is sensed by a similar receiver dipole. The ratio of the primary field and secondary fields is related to the conductivity of the subsurface.

In its natural (uncontaminated) state, groundwater acts as a relatively poor electrical conductor. However, the presence of inorganic contaminants can increase the groundwater electrical conductivity and thus the electrical conductivity of the saturated soil. Generally, ground conductivity depends principally on lithological characteristics, such as soil structure (coarser structure and smaller porosity producing lower conductivity), clay content (increasing clay fraction producing higher conductivity); soil moisture content (increasing moisture producing higher conductivity) and conductivity of included pore water (McNeill, 1987).

The conductivity of a water (electrolyte) is proportional both to the total number of ions in the solution and their mobility. The mobility of a particular ion depends on its diameter. For example, H^+ has a mobility of 36.2 x 10'' m^2/sec V and SO_4^- a mobility of 8.3 X 10^{-8} m^2/sec V (Keller and Frischknecht, 1966). For average unconsolidated soil, an increase of approximately 25 mg/L of total dissolved solids (TDS) of sodium chloride (NaCl) to soil water will increase the saturated bulk soil conductivity by 1 mS/m (McNeill, 1987).

Given the factors affecting the measurements of EM surveys, these surveys' use in detecting seepages from mining wastes and mine workings can lead to mis-interpretation without sufficient background on the site. In acid mine drainage water, TDS can be very high, reaching values as high as 100,000 mg/L. Tailings material has clay-like characteristics and underground workings can contain metals and reinforced concrete.

An Orion model 140 electrical conductivity meter was used to measure surface, bottom and sediment conductivity in Confederation Lake, Boomerang Lake and in seepage and piezometer samples. The results of the surveys with the two different instruments are compared. Increases in both readings at the same locations are considered as a point of AMD seepage. The conclusions are confirmed with water samples.

3.2 Mill Site and Confederation Lake Sediment Survey

The EM31 survey results are presented in Figures la, 1b and I c and show conductivity to a depth of up to 6 m. In Figures I d and le, the results are plotted of the survey with **EM34-3**, with depth penetration of up to 7.5m and 15 m, respectively.

A number of areas of anomalous conductivity can clearly be seen on each map. An analysis of the readings focusing on different exploration depths shows that anomaly sources occur at shallow depths. In the area around the demolished mill, shaft and mine buildings, the conductivities range from 15 to 20 mS/m to greater than 35 mS/m. Since this area has been re-contoured with waste rock, this surficial cover may mask EM responses from lower depths.

Elsewhere, the surveys with coil spacings of 10 and 20m, representing depth penetrations of about 7.5 and 15m respectively, identified discrete areas of high conductivity which are interpreted to reflect seeps. The anomaly between line 0 and 50E has its highest conductivities on the survey carried out with a 10m dipole separation, with responses decreasing on the survey with the 20 m separation. At the anomaly location, the entrance to the mine portal has been buried under waste rock.

The high conductivity anomaly between line 150E and 200E is seen at all depths (Figure I a - le). Although representing a real conductivity contrast, initially the source of this anomaly could not be identified with any certainty. However, during the excavation of the groundwater diversion ditch, this area was identified as the lime mixing silo.

The results depicted inwigwes la, 1d and I e represent a winter survey conducted in March 1992, when the site was under about 1 m of snow cover. In September 1993, the survey was repeated without the snow cover (Figures I b and lc).

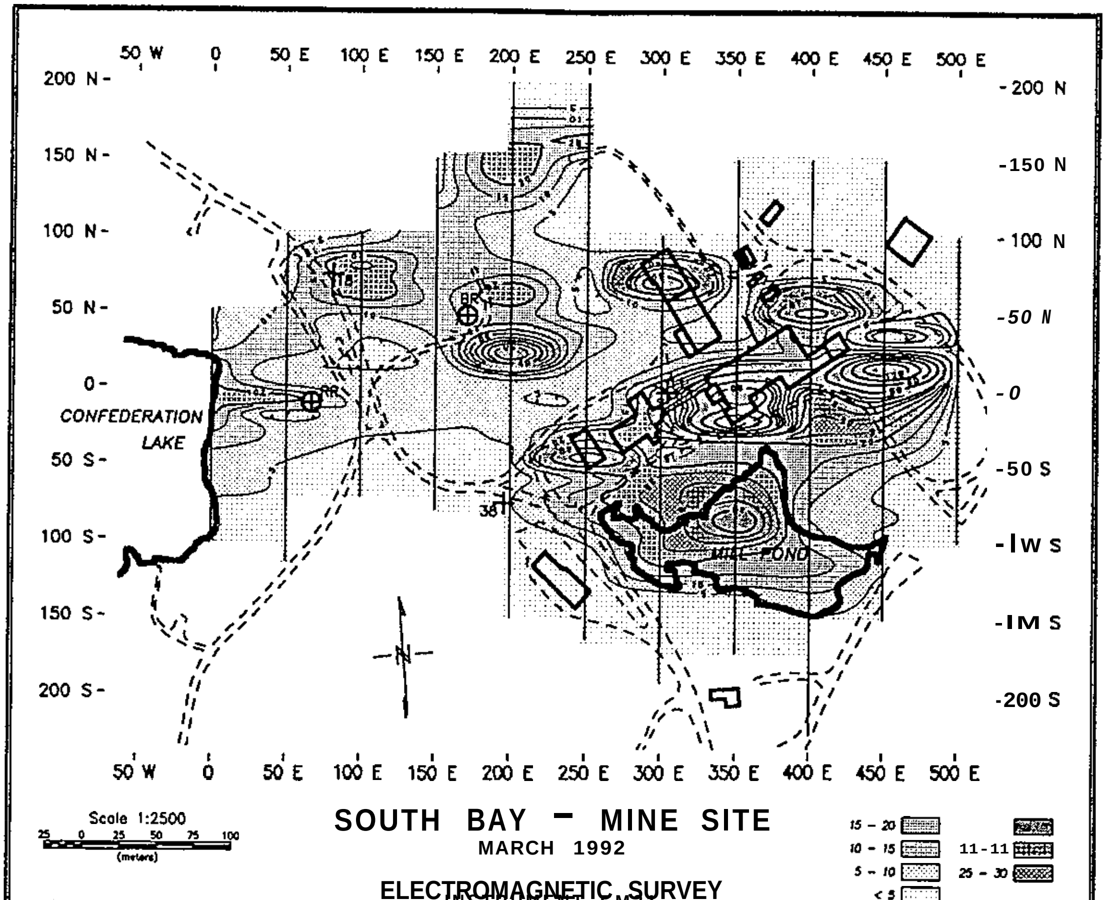


Figure la:

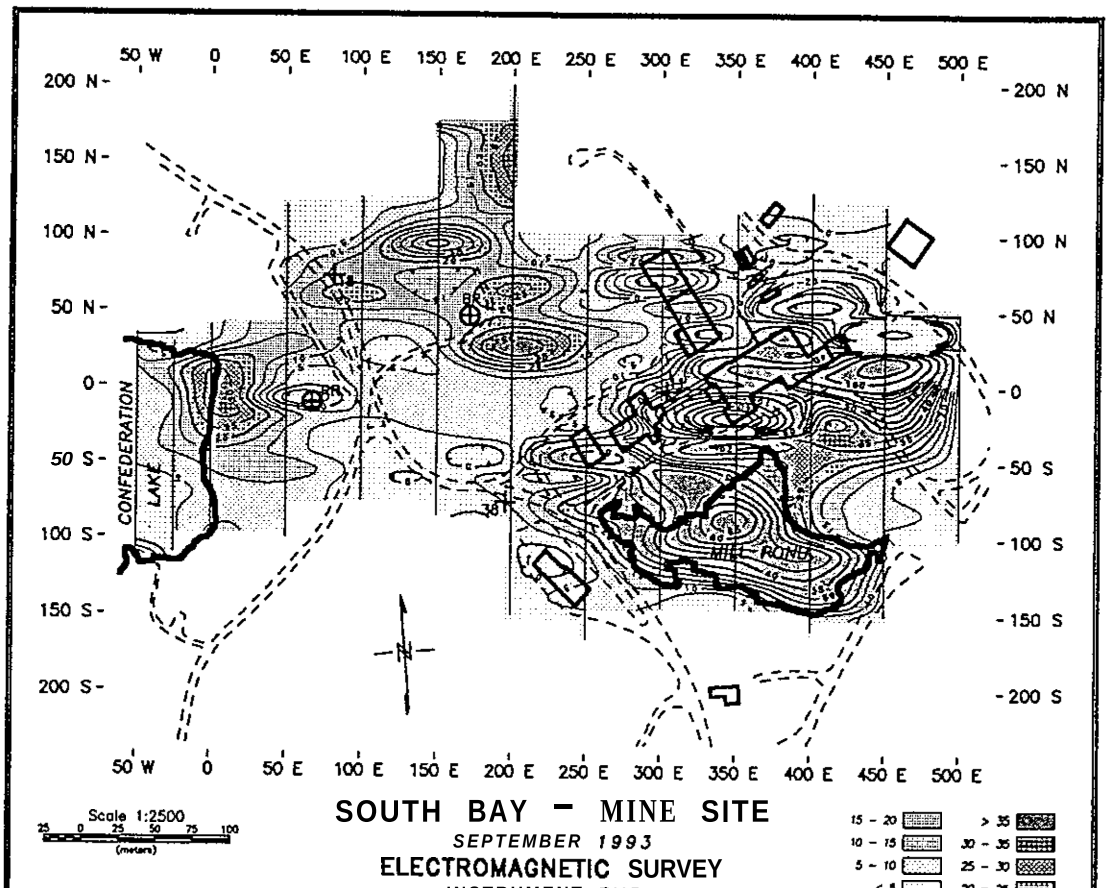


Figure lb:

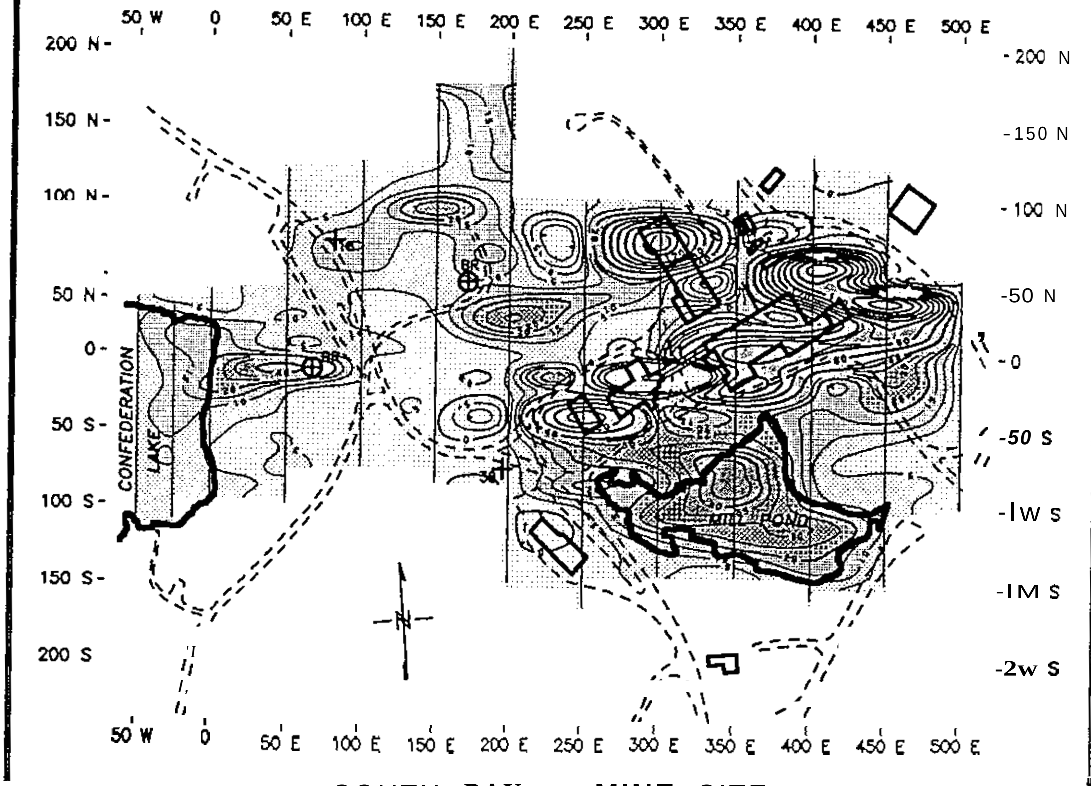


Figure Ic:

SOUTH BAY - MINE SITE

SEPTEMBER 1993

ELECTROMAGNETIC SURVEY

INSTRUMENT EM31

HORIZONTAL DIPOLE MODE

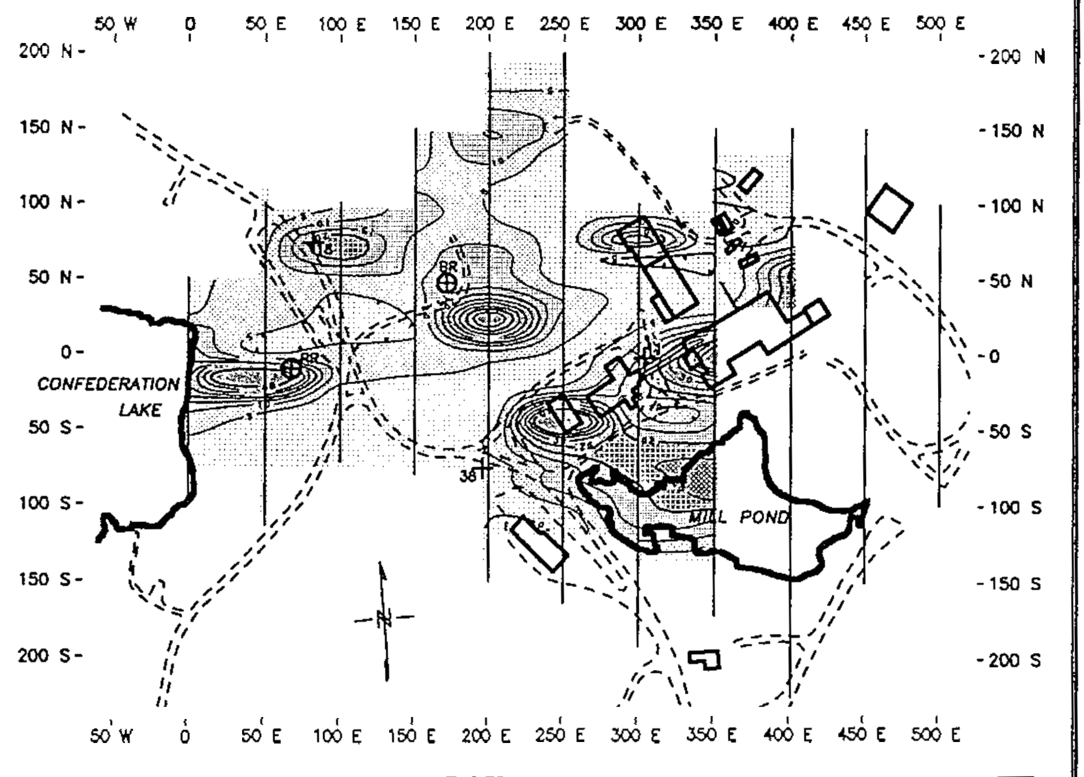


Figure Id:

SOUTH BAY - MINE SITE

MARCH 1992

ELECTROMAGNETIC SURVEY

INSTRUMENT EM34-3

HORIZONTAL DIPOLE MODE

DIPOLE SEPARATION 10 m

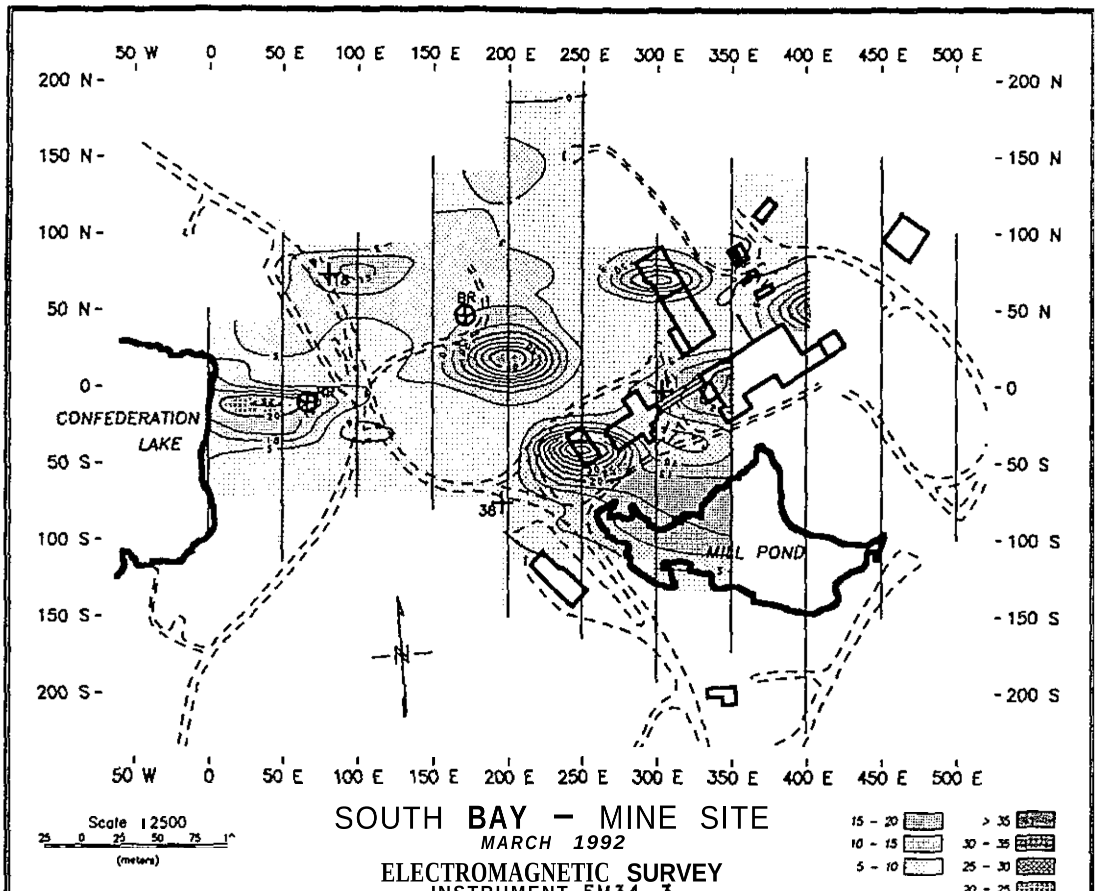
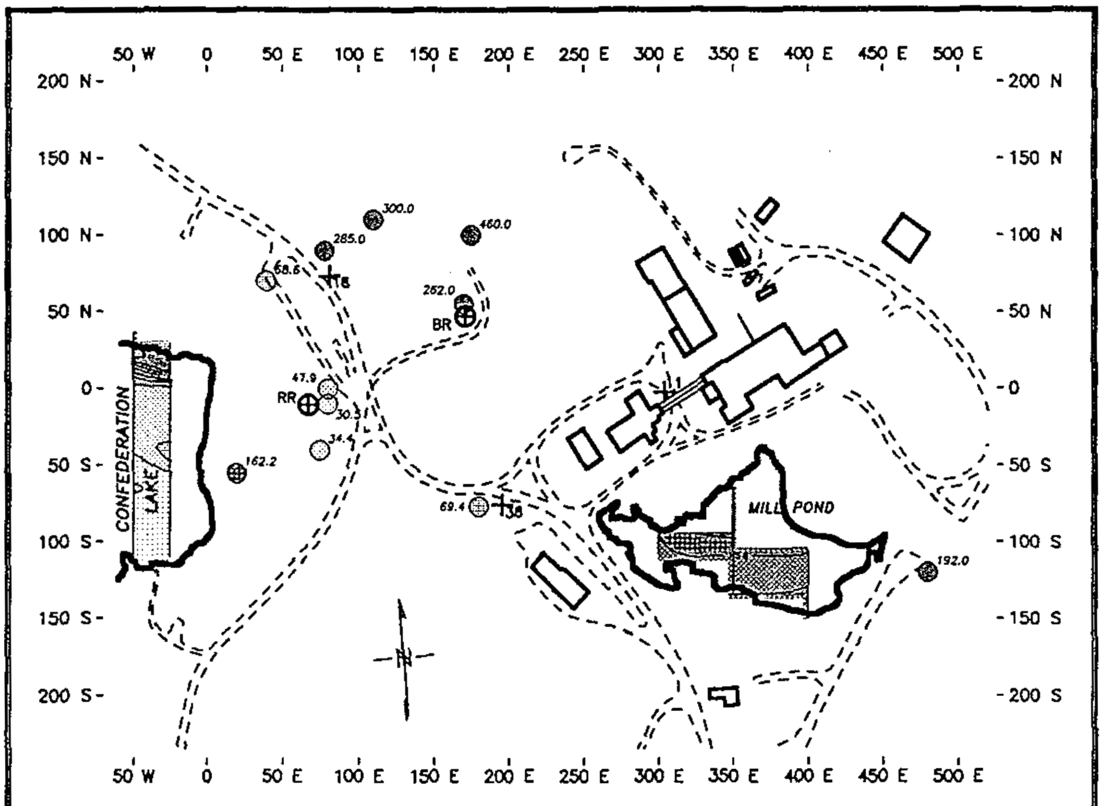


Figure Ie:

Both surveys depicted in Figure I a and Figure I b were conducted in the vertical mode to explore to a depth of about 6 m. A large seasonal difference is reflected in the increased conductivities in the immediate area of Mill Pond during the summer months. This is due to an increased water temperature and absence of the snow cover. The other anomalies described previously remained the same.

The results depicted in Figure 1c, represent a survey conducted in a horizontal mode with the exploration depth shallower, to about 2 m. Comparing these results with Figure 1b allows for an assessment of the portal seepage plume moving towards Confederation Lake. The shallow plume in the sediment at a depth up to 2 m extends over approximately half of the east shoreline of the small bay.

In Figure 2, the results of the Orion specific conductivity survey, measured at the sediment-water interface in Confederation Lake, are presented for two transects 25 and 50m away from the shore. An EM31 electromagnetic survey was carried out simultaneously with the Orion survey, and these results are depicted in Figures 1b and Ic.



Scale 1:2500 (meters)

SOUTH BAY – MINE SITE
SEPTEUQER 1993

BOTTOM WATER & BOREHOLE
Figure 2: SPECIFIC ELECTRICAL **CONDUCTIVITY**

Conductivity in mS/m

Interpolation is only possible between the two survey lines with the specific conductivity measurements. The anomalous trends identified by the Orion survey correlate well with those detected with the EM31 unit. The south side of the beach is uncontaminated and the sediment plume is greater on the north shore of the beach. This data suggests that in relatively homogenous material such as the fine lake bottom sediments, the data for specific conductivity and the electrical conductivity concur. It can be concluded that the seepage is flowing through the sediments to depths of at least 6 m. The water depth along the survey lines ranges from 0.5 to 3 m, where the sediment-water interface is reached.

Conductivities in boreholes and water bodies on the mill site are also shown in Figure 2. Borehole specific conductivities are all in the range of clean water, ranging from less than 25 mS/m to 50 mS/m. Good correlation is also noted between the specific conductivity and the electrical conductivity measurements for Mill Pond (Figures la - lc and Figure 2). The bottom of this pond is comprised of bedrock, providing a homogenous background against the measurements obtained from the water.

In Figure 3, the pH of the bottom water is plotted for all the water sampling stations and the transects in Confederation Lake. In the lake sediments, a good relationship exists in the distributions of low pH, specific conductivity and the EM conductivity. For boreholes, pH is not a good indicator of the presence of acid mine drainage.

It is concluded that a number of anomalies of increased conductivity were detected on all grids. At only one location, from the Mill Site into Confederation Lake, could an anomaly be directly linked to a known seepage. The EM survey data detected the seepage plume at a depth of **6** m, a feature which could not have been determined with the specific conductivity measurements which were taken at a depth of **1** to *2* metres at the sediment-water interface. Seepage is centred at the north of the mine site beach.

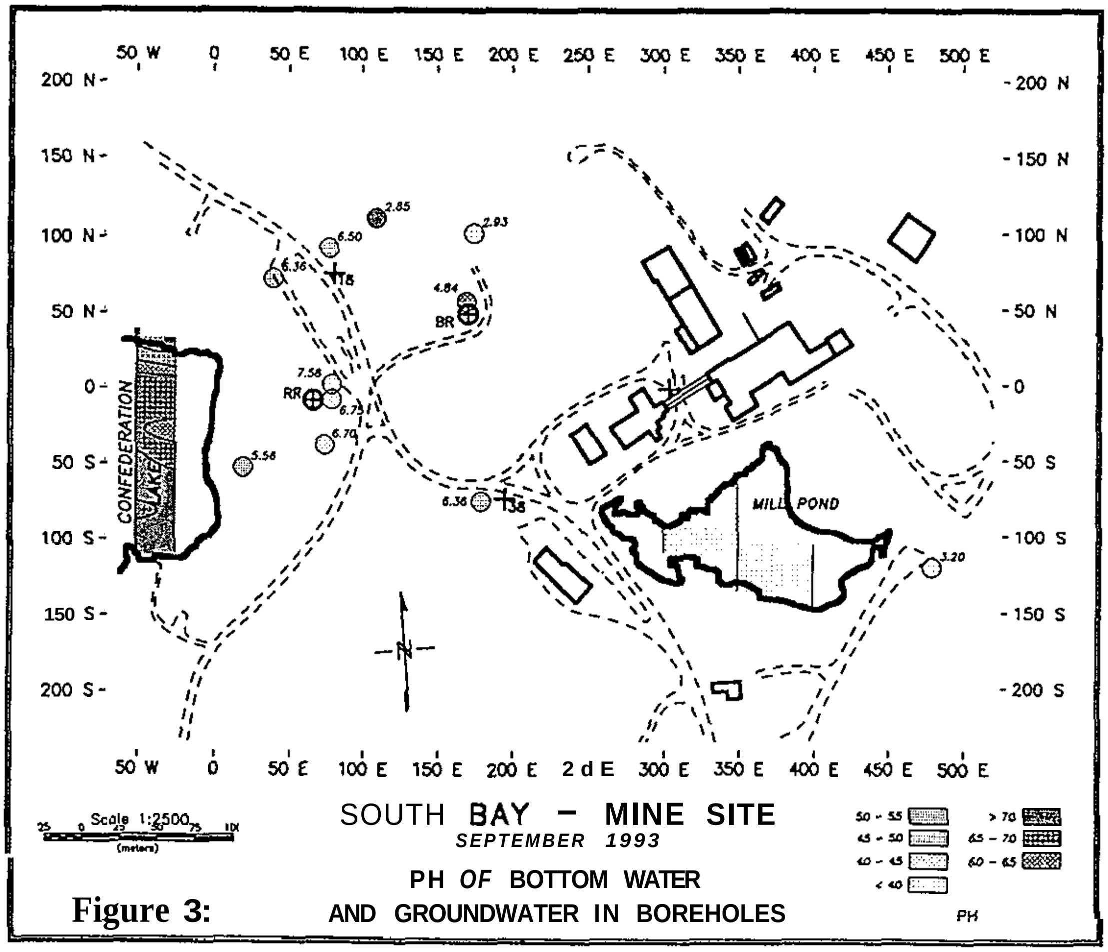


Figure 3:

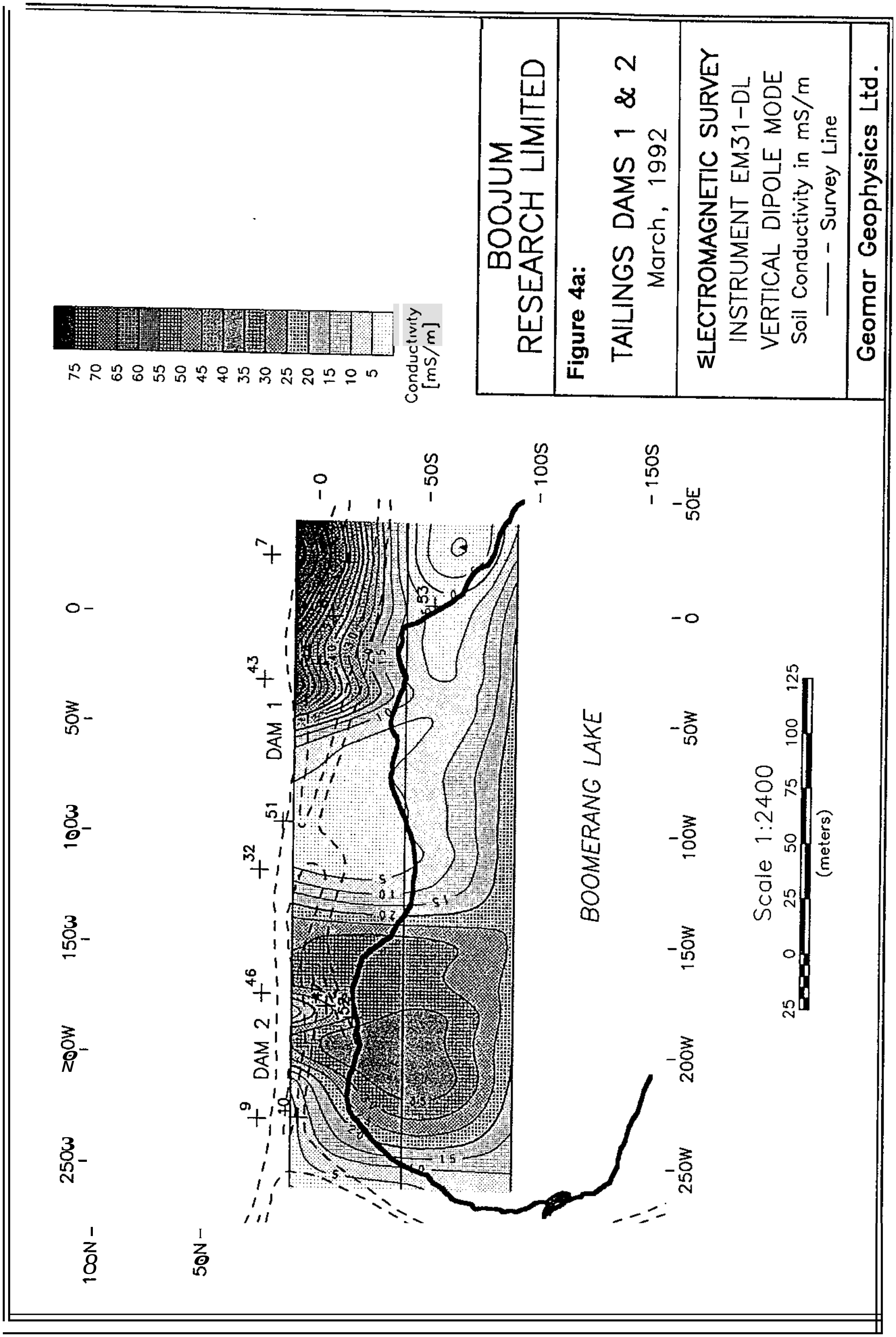
3.3 East and West Tailings Dams Survey

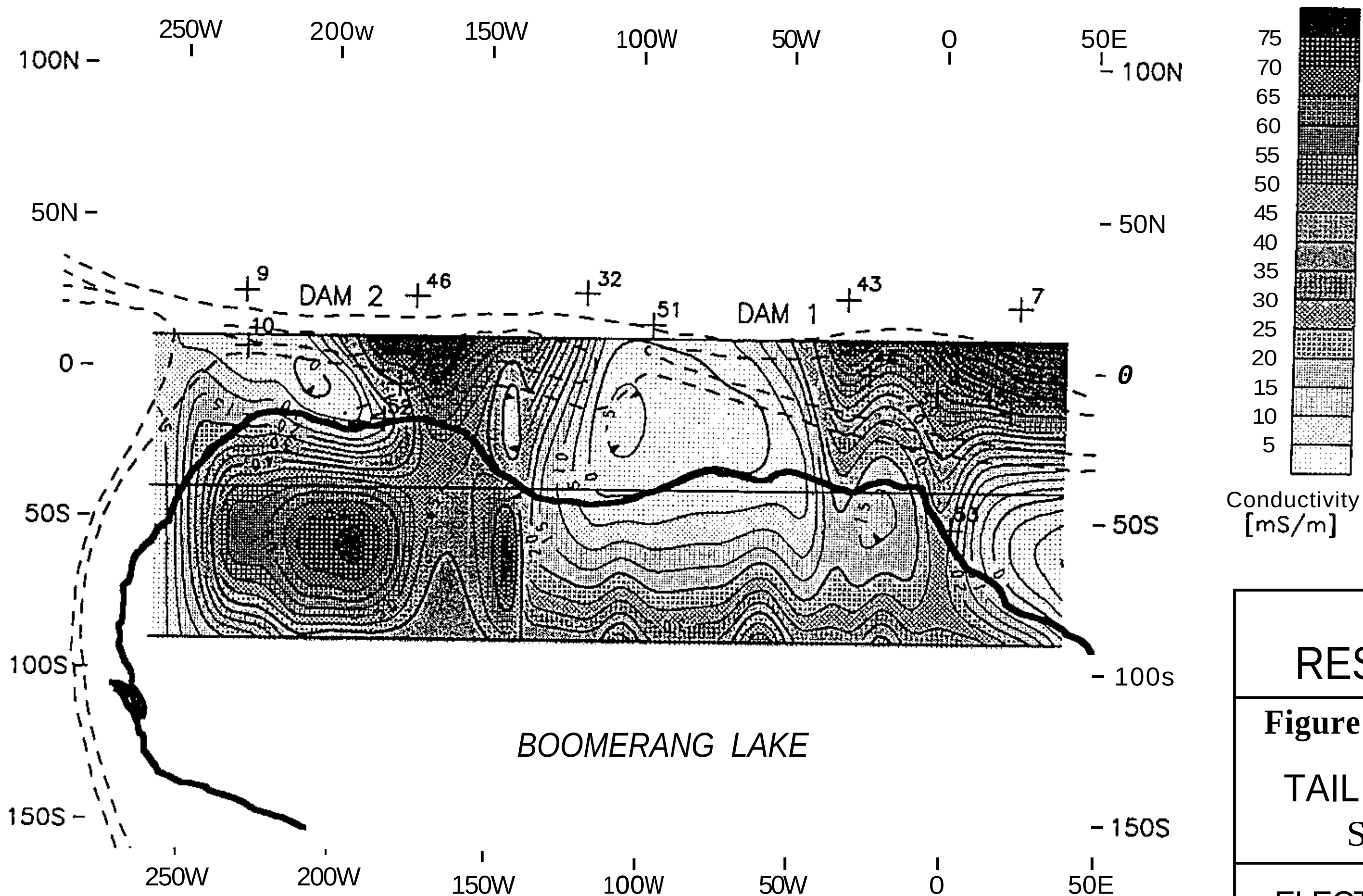
In March, 1992, an EM 31 electromagnetic survey, in vertical mode and exploring to a depth of **6** m, was conducted in the vicinity of the East and West Tailings Dams. The geophysical survey covered a 100m wide NW trending strip of tailings, tailings dam, adjacent shoreline and lake, straddling a 300m stretch of the NW shoreline of Boomerang Lake (Figure 4a). This same grid area was resurveyed in September, 1993 with the same EM31 instrument in both the vertical and horizontal modes (Figure 4b and 4c). Depth of penetration was approximately 2m while operating in the horizontal mode. In addition, specific conductivities at the sediment-water interface in Boomerang Lake (Figure 4d) and bottom pH (Figure 4e) were also measured with an Orion conductivity meter during the September 1993 survey.

Two EM31 anomalies, one at each dam were identified. Visual notations of seepage at the shoreline below the dam in the area of the West Dam anomaly clearly indicate that the EM response is due to seepage from the tailings. This seepage is leaking through the West Dam between survey lines 150W and 200W (Figures 4a - 4c). In addition, anomalous responses between 50E and 50W suggest that additional seepages may also be passing through the East Dam at *two* locations, but are not as extensive as at the West Dam. A low conductivity response was returned from the outcrop area located between the two dams.

The results of measurements of the specific conductance at the sediment-water interface (Figure 4d) verify the EM survey results. Specific conductance readings were high at the bottom of Boomerang Lake below the west dam, while the readings were homogeneously low at the bottom of Boomerang Lake below the east dam.

The pH of Boomerang Lake at the sediment-water interface was typically in the range of pH 3 to 4. However, the pH was 8 to 9 in one area near the shore below the West Dam. The high pHs are due to residual lime in sediments from treatment efforts in the 1980s.


BOOJUM
RESEARCH LIMITED
Figure 4a:
TAILINGS DAMS 1 & 2
March, 1992
ELECTROMAGNETIC SURVEY
INSTRUMENT EM31-DL
VERTICAL DIPOLE MODE
Soil Conductivity in mS/m
— - Survey Line
Geomar Geophysics Ltd.
Conductivity [mS/m]
75 70 65 60 55 50 45 40 35 30 25 20 15 10 5
DAM 1
DAM 2
BOOMERANG LAKE
Scale 1:2400
(meters)
25 0 25 50 75 100 125
100N
50N
0
50S
100S
150S
250W 200W 150W 100W 50W 0 50E



Scale 1:2400

25 0 25 50 75 100 125

(meters)

BOOJUM RESEARCH LIMITED

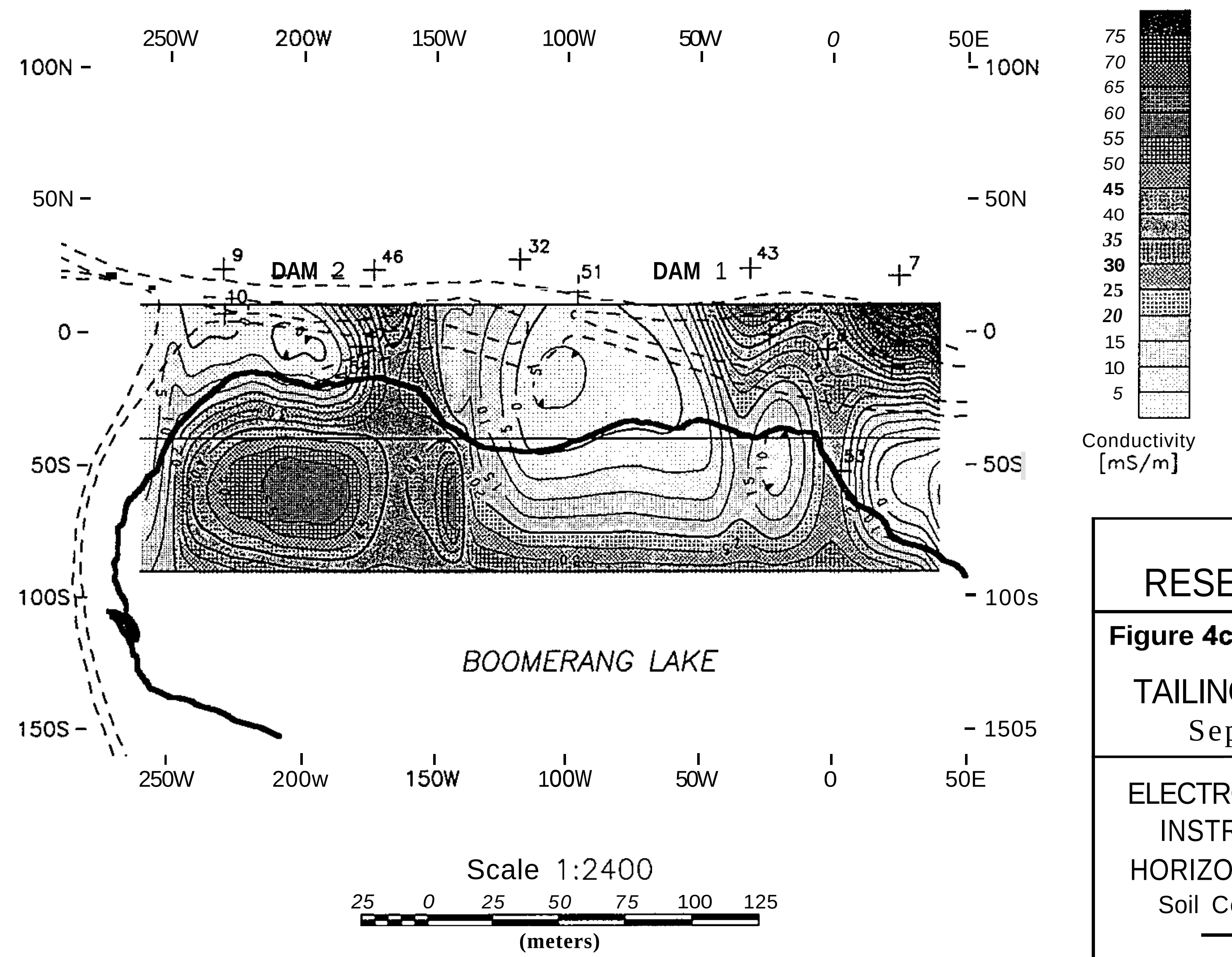
Figure 4b:

TAILINGS DAMS 1 & 2

September, 1993

ELECTROMAGNETIC SURVEY
INSTRUMENT EM31-DL
VERTICAL DIPOLE MODE
Soil Conductivity in mS/m
——— Survey Line

Geomar **Geophysics** Ltd.



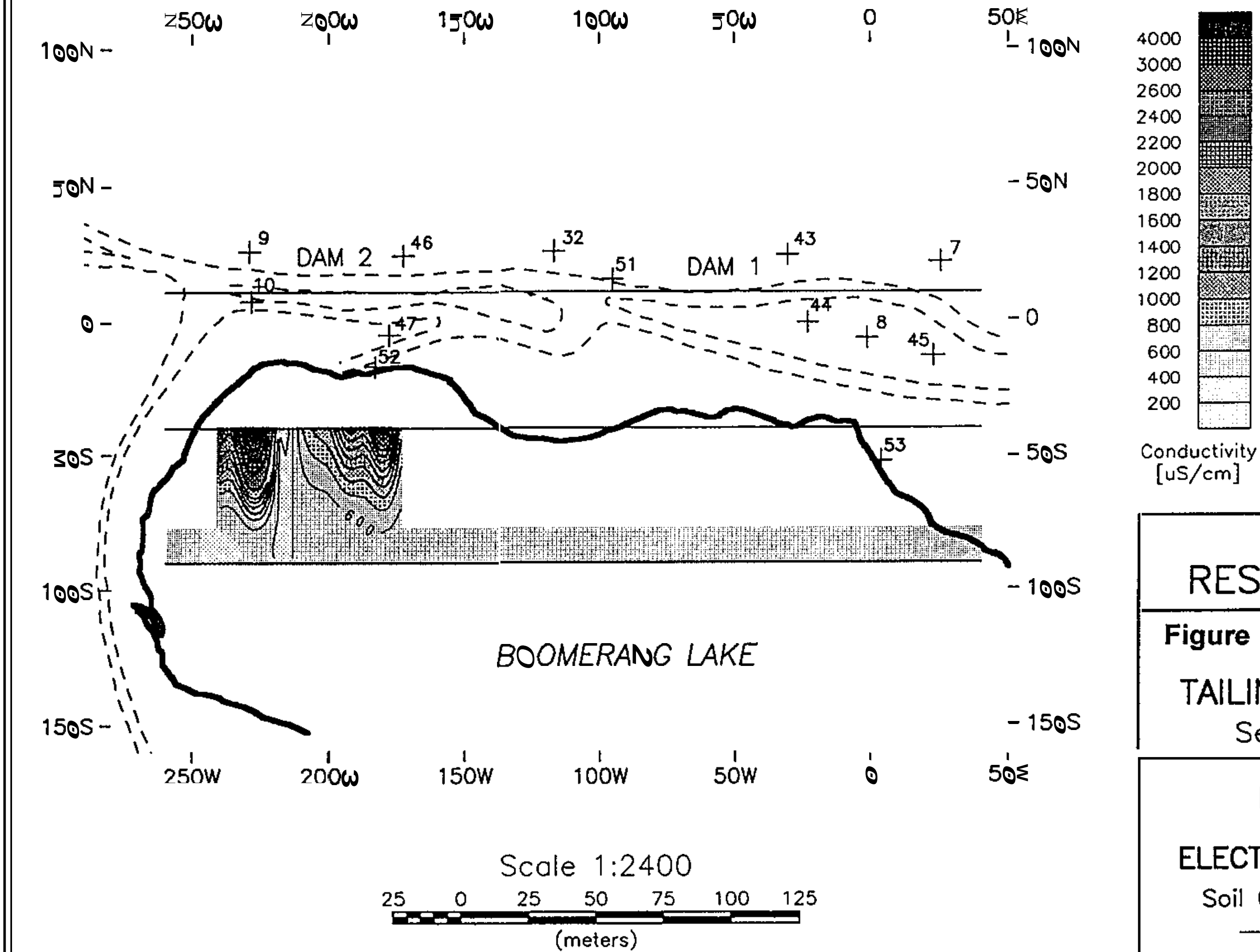
BOOJUM RESEARCH LIMITED

Figure 4c:

TAILINGS **DAMS** 1 & 2
September, 1993

ELECTROMAGNETIC SURVEY
INSTRUMENT EM31-DL
HORIZONTAL DIPOLE MODE
Soil Conductivity in mS/m
Survey Line

Geomar Geophysics Ltd.



BOOJUM RESEARCH LIMITED

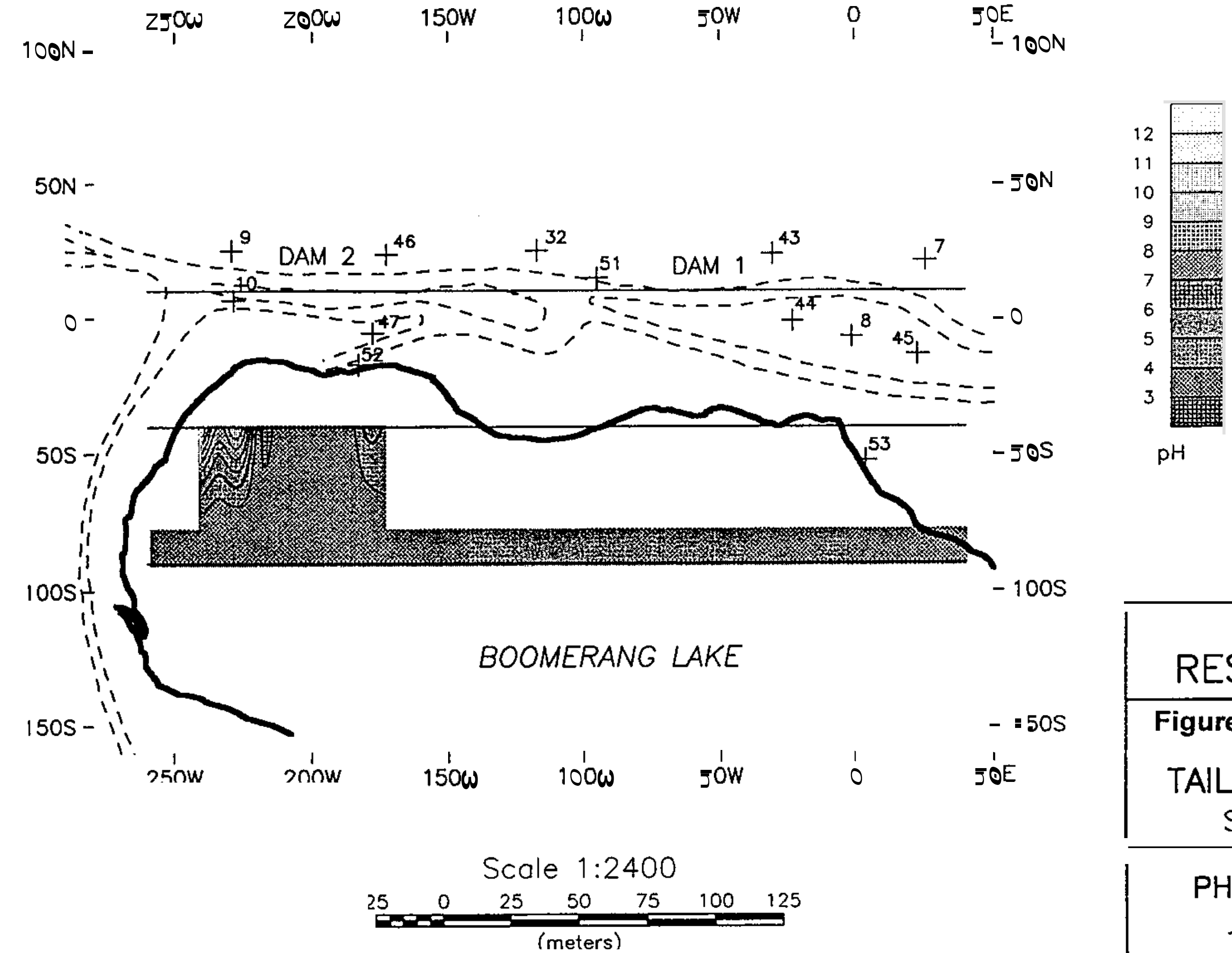
Figure 4d:

TAILINGS DAMS 1 & 2
September, 1993

BOTTOM WATER SPECIFIC ELECTRICAL CONDUCTIVITY

Soil Conductivity in uS/cm
—— - Survey Line

Geomar Geophysics Ltd.



BOOJUM RESEARCH LIMITED

Figure 4e:

TAILINGS DAMS 1 & 2

September, 1993

PH OF BOTTOM WATER

——— - Survey Line

Geomar Geophysics Ltd.

-

3.4 Town Site Survey

In March, 1992, two electromagnetic surveys were conducted between the tailings and the town site in the vicinity of the Tailings Diversion Ditch. The first survey was with an EM31 unit in vertical mode with a 6m depth penetration (Figure 5a), while the second survey utilized an EM34 unit with a 20 m coil separation and a 15m depth penetration (Figure 5b).

The Tailings Diversion Ditch, although not shown in the figures, extends eastward from OE and ON, through and past 200E and 25S. It was constructed to direct a contaminated groundwater plume towards Boomerang Lake. The flow is estimated at 10,550 m^3 per year, originating in the tailings and travelling westward through the townsite towards Confederation Lake. In September, 1993, the same grid was resurveyed using the EM31 instrument in the vertical mode with a depth penetration of 6 m (Figure 5c), and in the horizontal mode with a 2 m depth penetration (Figure 5d).

The results of the March, 1992, survey reveal two high conductivity anomalies (Figures 5a and 5b). Very similar results were obtained during the September, 1993 survey (Figures 5c and 5d). The west anomaly likely represents seepage from the tailings moving south. Since the anomaly is minor at depth (Figure 5b) the Tailings Diversion Ditch is likely intercepting this plume.

The east anomaly appears to be isolated (Figures 5a-5d), and shallow as the readings becomes weaker with depth (Figure 5b). This anomaly may reflect residual seepage deposited prior to the construction of the Tailings Diversion Ditch.

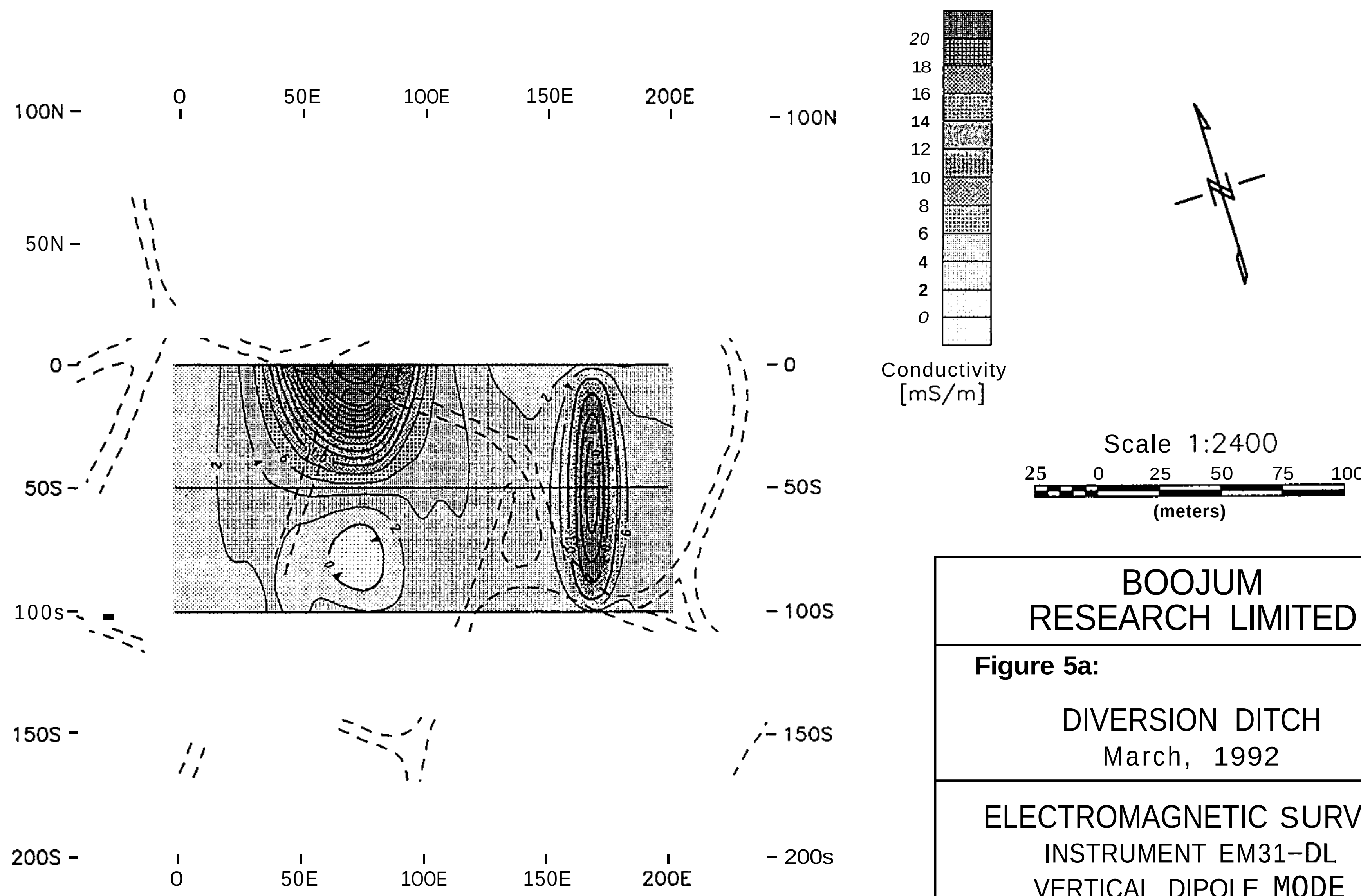


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Figure 5a:

DIVERSION DITCH
March, 1992

ELECTROMAGNETIC SURVEY
INSTRUMENT EM31-DL
VERTICAL DIPOLE MODE
Soil Conductivity in mS/m
——— - Survey Line

Geornar Geophysics Ltd.

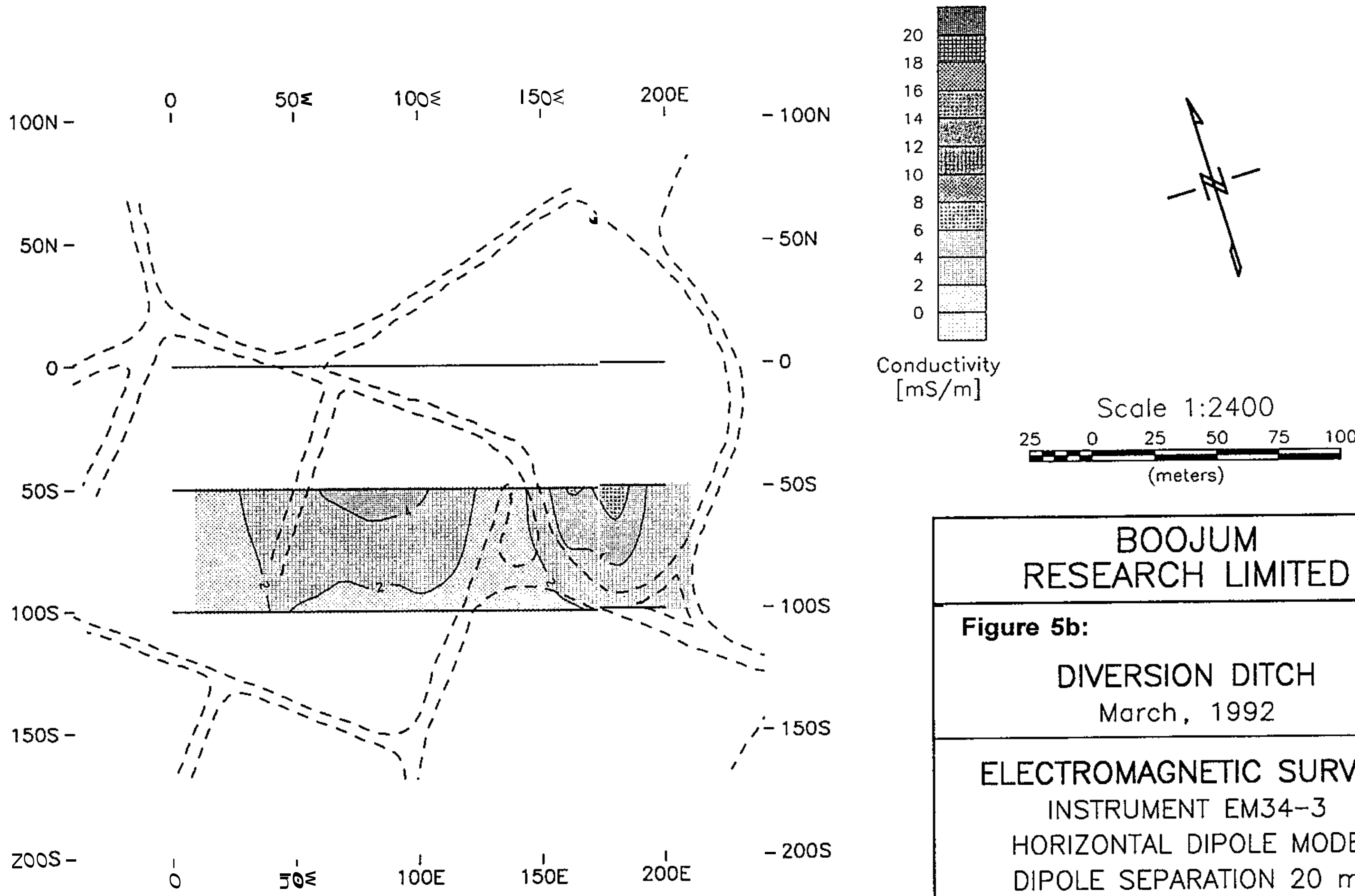

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Figure 5b:

DIVERSION DITCH
March, 1992

ELECTROMAGNETIC SURVEY
INSTRUMENT EM34-3
HORIZONTAL DIPOLE MODE
DIPOLE SEPARATION 20 m
Soil Conductivity in mS/m
——— - Survey Line

Geomar Geophysics Ltd.

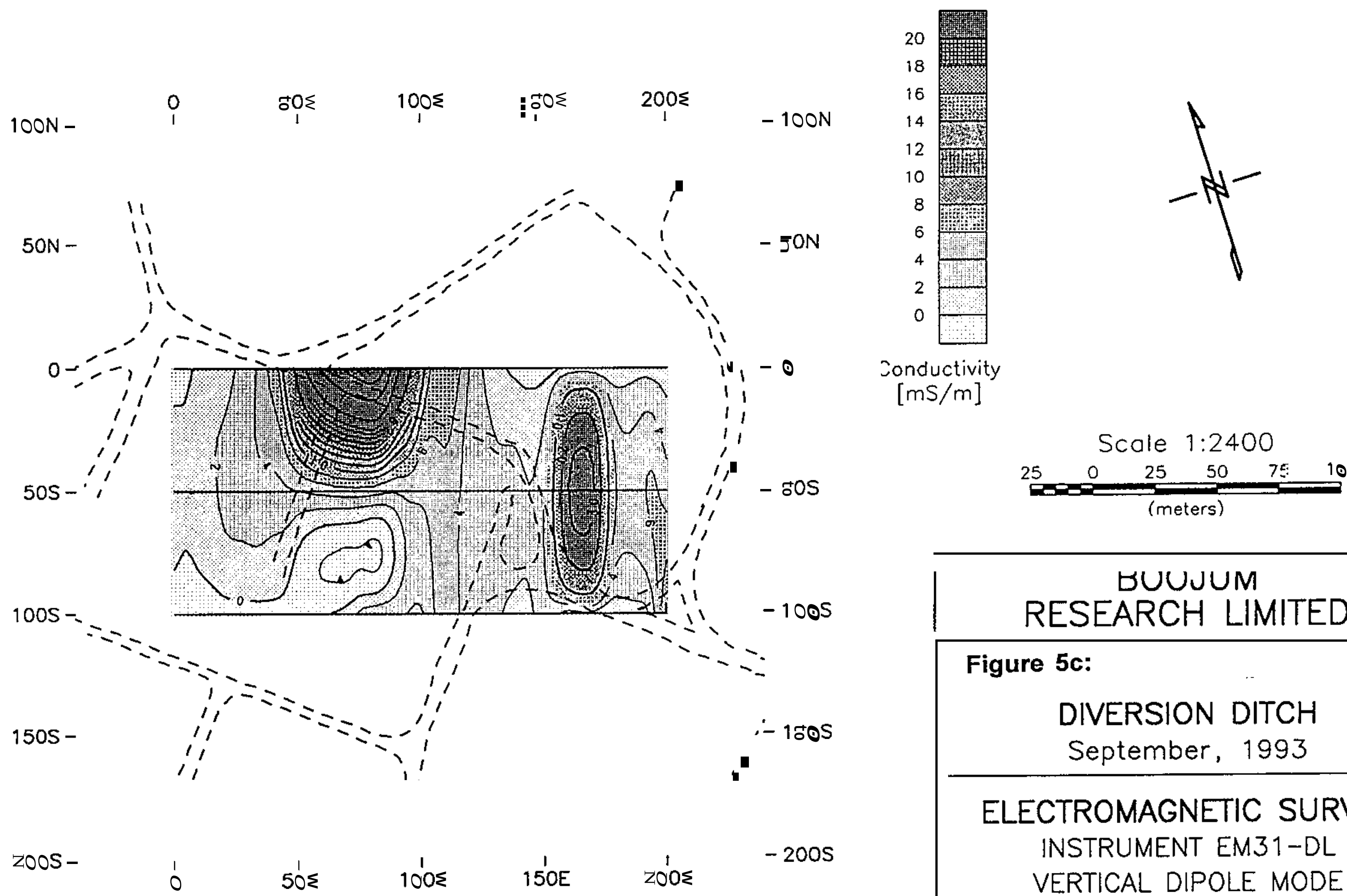

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Figure 5c:

DIVERSION DITCH
September, 1993

ELECTROMAGNETIC SURVEY
INSTRUMENT EM31-DL
VERTICAL DIPOLE MODE
Soil Conductivity in mS/m
——— - Survey Line

Geomar Geophysics Ltd

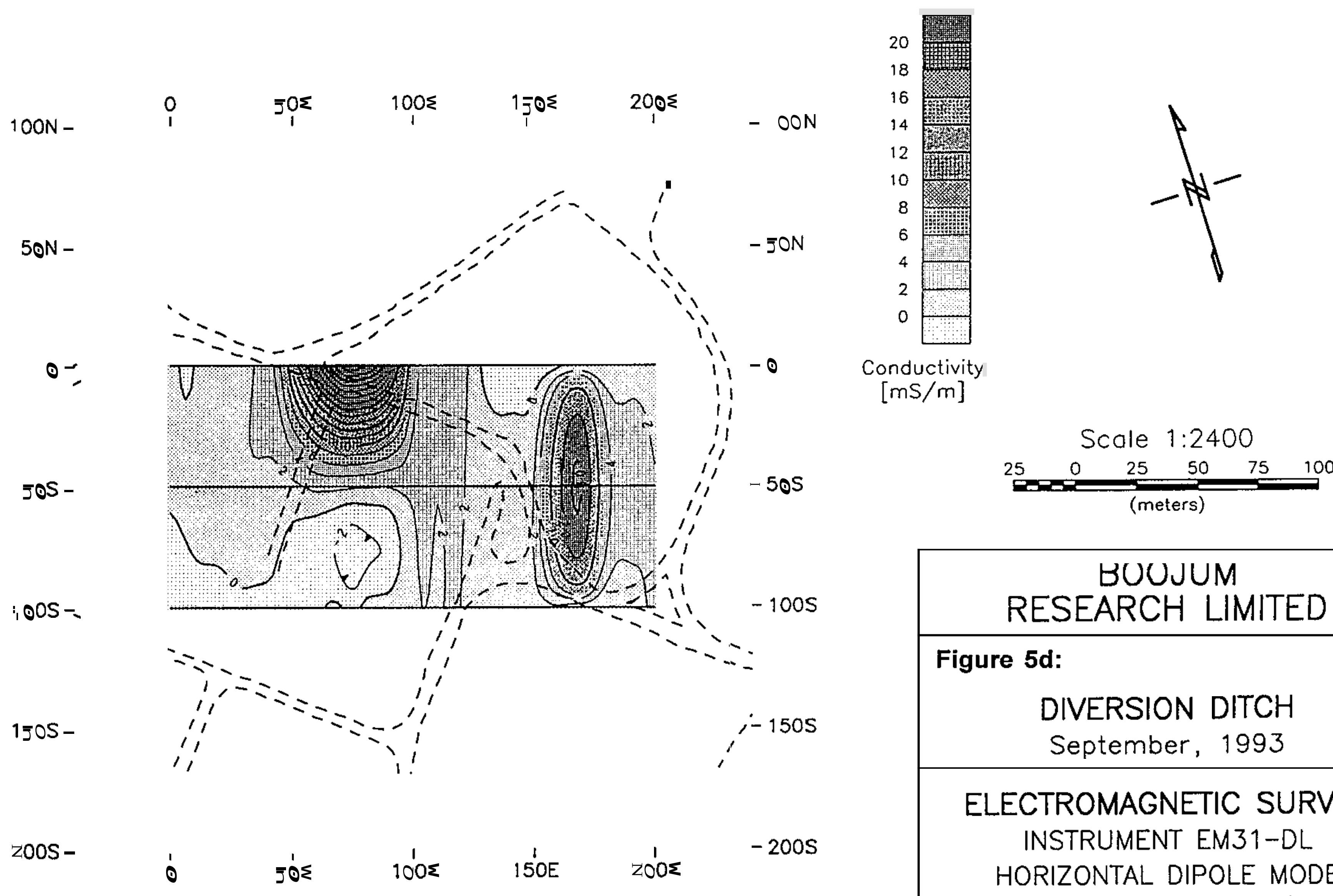

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Figure 5d:

DIVERSION DITCH
September, 1993

ELECTROMAGNETIC SURVEY
INSTRUMENT EM31-DL
HORIZONTAL DIPOLE MODE
Soil Conductivity in mS/m
——— – Survey Line

Geomar Geophysics Ltd.

3.5 Chemical Characteristics Of Mill Site Seepages

The groundwater discharge through the sediments in Confederation Lake close to the Mill Site, and the seepage emerging on the surface at the Mill Site beach, needed to be reduced. As a result, the Backfill Raise Diversion Ditch was constructed, with the intent of reducing the flow of groundwater to Confederation Lake through the sediment, and of stopping the surface seepage flow from the old buried Portal Raise, from the Adit and from the Backfill Raise. The location of the seepages and the piezometers at the Mill Site, along with the approximate shape of the Backfill Raise Diversion Ditch, are shown in Map 2.

For the groundwater flow, quantitative data other than those from the old piezometers (M18 and M38) were not available. Data for the surface seepages, which are transient in nature, did not exist prior to fall of 1991 (one sample taken on May 14, 1989, from BR-13C, pond directly above BR-13, contained elevated Zn). A summary of BR-13 and BR-13C water quality and flows is provided in Table 6.

Using the flows sporadically measured at BR-13, estimated total loadings can be calculated for the 167 days of the year when the seepages are not frozen (Table 7). In 1991, the loadings to Confederation Lake from the BR-13 surface seepage were about 2.1 tonnes of Zn, 0.3 tonnes of Fe, and 5.1 t of acidity and the same order of magnitude for 1992.

The Backfill Raise Ditch, excavated between November, 1992 and January, 1993, reduced both the zinc, iron and acidity concentrations, and the flow at the BR-13 station (Table 7). Loadings for 1993 were 0.04 t Zn, 0.002 t Fe and 0.05 *t* acidity. By 1994, seepage flow was no longer observed at the BR-13 station. That same year, the water level in the BR-13C pool had dropped by approximately 0.2 m, and the water contained, on average, 13 mg/L Zn, only 40 mg/L acidity and virtually no iron (Table 6).

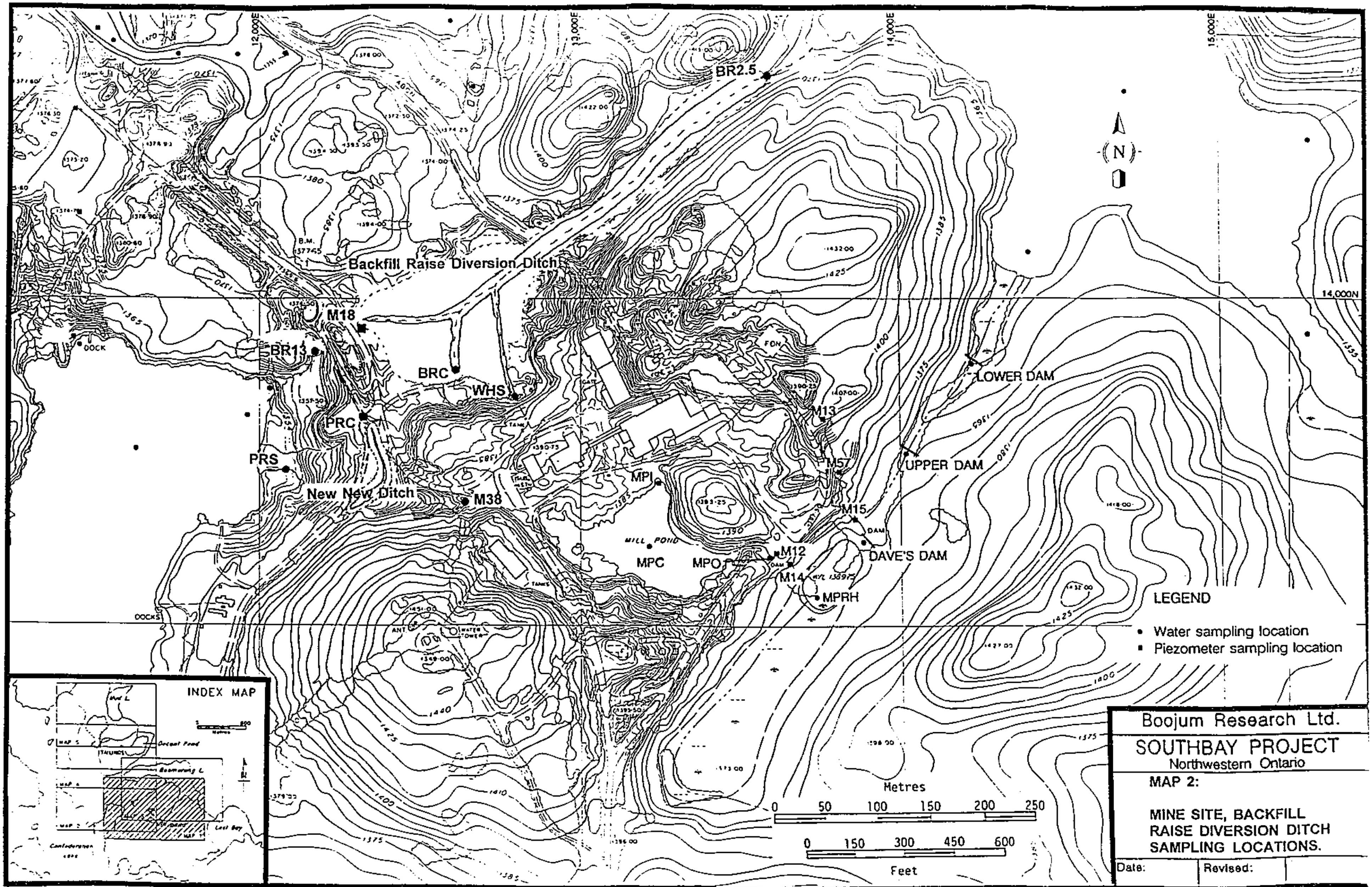

BR2.5
Backfill Raise Diversion Ditch
M18
BR13
BRC
WHS
PRC
PRS
New New Ditch
M38
MPI
MPC
MPO
M12
M14
MPRH
M13
M57
M15
LOWER DAM
UPPER DAM
DAVE'S DAM
DOCK
DOCKS
MILL POND
14,000N
12,000E
13,000E
14,000E
15,000E
N
INDEX MAP
LEGEND
• Water sampling location
▪ Piezometer sampling location
Metres
0 50 100 150 200 250
0 150 300 450 600
Feet
Boojum Research Ltd.
SOUTHBAY PROJECT
Northwestern Ontario
MAP 2:
MINE SITE, BACKFILL
RAISE DIVERSION DITCH
SAMPLING LOCATIONS.
Date:
Revised:

Table 6: Chemistry of Sampling Location BR-13 and BR-13C, Confederation Lake Shore

Year	Date	Assay.	Station	Concentrations										Flow
		#	#	Cu	Zn	Fe	Pb	pH	[H+]	Ni	Acidity	Alkalinity	Sulfate	
				mg/L	mg/L	mg/L	mg/L			mg/L				L/s
1991	Average			3.74	238.33	38.07	0.753		6.4E-04	0.70	574.3		1647.0	0.62
1992	Average			0.93	134.30	10.93	0.532		8.7E-05	0.55	306.0	17.5	847.5	0.77
1993	Average				19.20	1.03			1.0E-06		26.4			0.14
1994	Average			0.06	13.39	0.13	0.03		1.0E-06	0.02	39.73	49.37	223.74	no flow
1991	25-Jun	2867	BR-13	6.22	295.00	47.2	< 0.260	3.00	1.0E-03	< 0.09	556.0		2067.0	NR
	26-Jul	3007	BR-13	< 1.00	199.00	44	< 1.000	3.14	7.2E-04	< 1.00	567.0		1386.0	NR
	25-Sep	3450	BR-13	4.00	221.00	23	< 1.000	3.72	1.9E-04	< 1.00	600.0		1488.0	NR
1992	13-Jul	3867	BR-13	1.00	173.00	13.7	1.000	3.63		1.00	201.5	17.5	1092.0	NR
	16-Jul	3876	BR-13	1.00	84.20	4.31	1.000	5.54	2.9E-06	1.00	172.5		507.0	0.16
	14-Aug	4019	BR-13	1.02	163.00	20.6	0.078	3.61	2.5E-04	0.12	505.0		1188.0	0.15
	16-Oct	4210	BR-13	0.68	117.00	5.1	0.050	4.90	1.3E-05	0.09	345.0			2.00
1993	11-Apr		BR-13		19.20	1.03		6.00	1.0E-06		26.4			0.14
1989	14-May	1040	BR-13C	5.90	881.00	9.3	0.400	5.60	2.5E-06	0.30			3774.0	0.00
1993	16-Jun		BR-13C					6.09	8.1E-07		48.2			0.00
	07-Sep	4555	BR-13C	0.04	12.80	0.217	0.025	6.56	2.8E-07	0.03	33.9	46.6	290.4	0.00
1994	28-Mar		BR-13C	Frozen, no water sample										No flow
	28-Apr		BR-13C	0.066	1.76	0.231	0.025	6.36	4.4E-07	0.01	10.3	65.1	22.02	NR
	18-Jun		BR-13C	0.072	13.5	0.118	0.025	5.74	1.8E-06	0.03	53.8	48.3	298.2	No flow
	30-Aug		BR-13C	0.038	24.9	0.049	0.025	6.12	7.6E-07	0.03	55.1	34.7	351	No flow

Table 7: Contaminant Loadings to Confederation Lake from BR-13, Confederation Lake Shore

Year	Averages								Loadings		
	Flow	(#)	Zn	(#)	Fe	(#)	Acidity	(#)	Zn	Fe	Acidity
	L/s		mg/L		mg/L		mg/L		kg/a	kg/a	kg/a
1991	0.62	*	238	4	38	4	574	4	2118	338	5105
1992	0.77	3	134	3	10.9	3	306	4	1492	121	3400
1993	0.14	1	19	1	1.0	1	26	1	39	2.1	53
1994	no flow	4	13	3	0.13	3	40	3	No surface flow/loading		

* Estimated as 80% of 1992 flow

Considering these results, it appears that the Diversion Ditch has successfully achieved its goal of reducing, or even eliminating the contaminant loading into Confederation Lake.

In 1992, the Portal Raise Seepage (PRS) was flowing at an average rate of 0.41 *Us*, and averaging 53 mg/L Zn, 1.5 mg/L Fe, and 103 mg/L acidity (Table 8). The zinc loading for a 167 day flow period for 1992 was 0.3 t, while the iron and acidity loadings were 0.009 t and 0.6 t, respectively (Table 9). Following excavation of the Backfill Raise Ditch in late 1992, flows diminished at PRS to 0.03 L/s on average (1993). The low average flow rate continued in 1994, at 0.01 ***Us.*** With this greatly reduced flow rate following ditch excavation, zinc, iron and acidity loadings at PRS in 1993 and 1994 were an order of magnitude lower than the 1992 loadings.

3.6 Hydrological Implications Of Ditch Construction

Figures 6 and 7 present the water level elevations in mine site piezometers and in BRC and PRC measured between October 1986 and October 1993. Water level elevations taken between March 1992 and October 1993 are depicted in Figures 8 and 9. Up-scaled elevations in pairs PRC-BRC, BRC-M18 and PRC-M38 between March 1992 and October 1993 are presented in Figures 10 to 12. The first set of data collected during and after ditch completion up to June 1993, indicates that "spring peak" in M18 did not occur, and that the water level elevation is below minimums for 1989-1992 (Figures 6 and 10).

Water level elevation measurements in PRC and BRC, as presented in Figure 12, suggest that the water levels behave similarly in both seepages. The BRC seepage does not appear to drain towards the ditch, as the water level is 0.56 m higher than the bottom elevation of the ditch (414.11). A hole, made in the concrete structure of the Backfill Raise Cap, produces about 1.6 L/min of water. It was concluded that PRC is connected to BRC somewhere through the mine workings.

Table 8: Chemistry of Sampling Location PRS, Confederation Lake Shore

Year	Date	Assay. #	Station #	Cu mg/L	Zn mg/L	Fe mg/L	Pb mg/L	pH	[H+]	Ni mg/L	Acidity	Alkalinity	Sulfate	Flow L/s
				Concentrations										
1992	Average			5.50	53.40	1.47	0.516		7.9E-05	0.51	102.6	20.0	427.7	0.41
1993	Average			2.67	110.73	4.72	0.025		2.0E-06	0.08	209.4	2.6	991.5	0.03
1994	Average			7.26	132.80	7.07	0.07		2.2E-06	0.06	278.58		863.25	0.01
1992	13-Jul	3868	PRS	1.50	46.20	< 1.00	< 1	5.62	2.4E-06	< 1.00	53	15.0	459.0	0.04
	16-Jul	3877	PRS	19.60	122.00	3.74	< 1	3.51	3.1E-04	< 1.00	264		525.0	1.46
	14-Aug	4038	PRS	0.58	22.20	0.20	< 0.025	5.64	2.3E-06	0.01	49		299.1	0.06
	16-Oct	4218	PRS	0.32	23.20	0.95	0.037	5.99	1.0E-06	0.01	44.2	24.9		0.08
1993	11-Apr		PRS		19.20	0.31		5.79	1.6E-06		81.7			0.05
	16-Jun		PRS					5.83	1.5E-06		44.2			0.05
	07-Sep	4565	PRS	1.71	137.00	7.20	0.025	5.56	2.8E-06	0.08	292.8	2.6	936.0	0.01
	09-Oct	4592	PRS	3.63	176.00	6.65	< 0.025	5.66	2.2E-06	0.08	419		1047.0	0.02
1994	28-Mar													No flow
	28-Apr			11.30	186.00	4.45	0.025	5.06	2.2E-06	0.07	399.9	1	1071	NR
	18-Jun			2.33	89.00	5.68	0.025	5.38	2.2E-06	0.05	58.3	5.6	648	0.007
	11-Jul			8.52	180.00	8.18	0.05	4.38	2.2E-06	0.08	409.8		1167	0.023
	30-Aug			6.88	76.20	9.95	0.17	4.29	2.2E-06	0.04	246.3		567	0.020

Table 9: Contaminant Loadings to Confederation Lake from Location PRS, Confederation Lake Shore

Year	Averages								Loadings		
	Flow	(#)	Zn	(#)	Fe	(#)	Acidity	(#)	Zn	Fe	Acidity
	L/s		mg/L		mg/L		mg/L		kg/a	kg/a	kg/a
1992 Average	0.41	4	53.40	4	1.47	4	102.6	4	315.9	8.7	606.7
1993 Average	0.03	4	110.73	3	4.72	3	209.4	4	48.5	2.1	91.7
1993 Before NND *	0.05	2	19.20	1	0.31	1	81.7	1	13.9	0.2	58.9
1993 After NND *	0.01	2	156.50	2	6.93	2	355.9	2	24.1	1.1	54.8
1994 Average	0.01	4	132.80	4	7.07	4	278.6	4	24.0	1.3	50.2

* Before, after excavation of NND ("New New Ditch") joining run-off from Antenna Hill with Portal Raise Cap (PRC).

Fig. 6: Mine site water levels
M38, M18, PRC, BRC

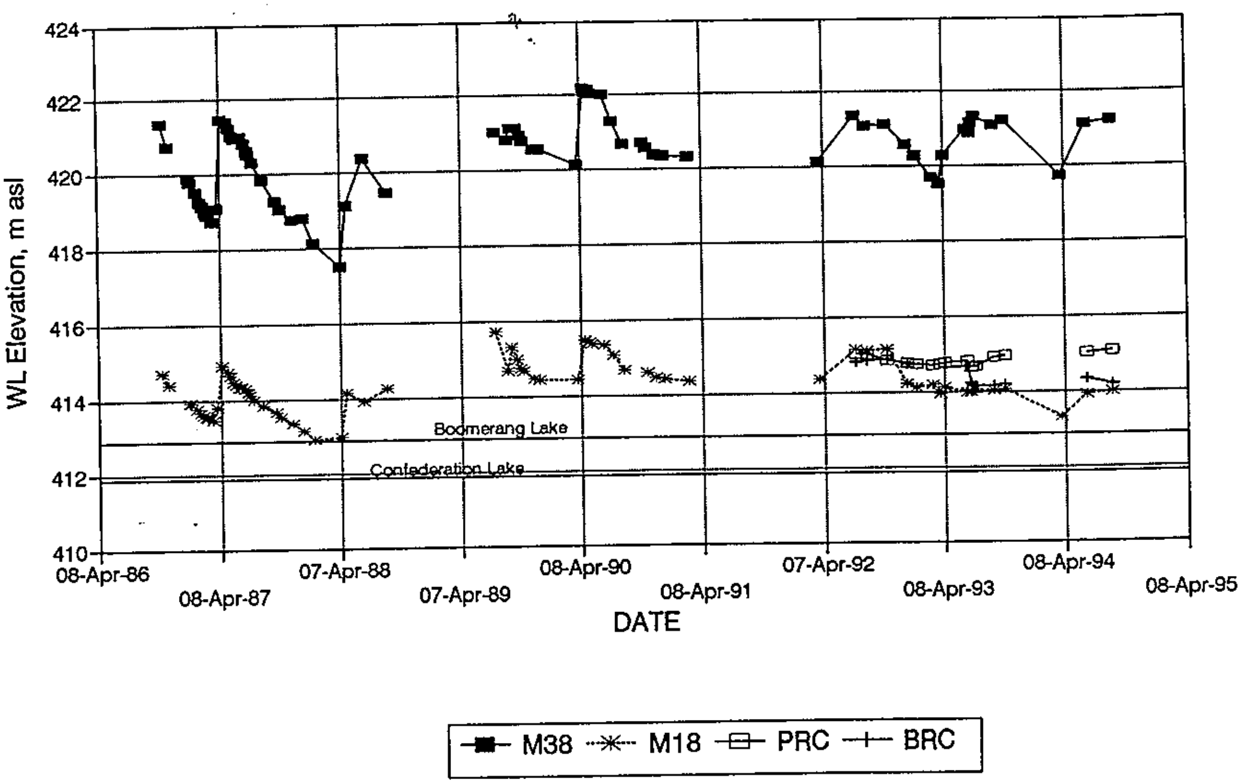


Fig. 7: Mine site water levels
M12, M13, M14, M57

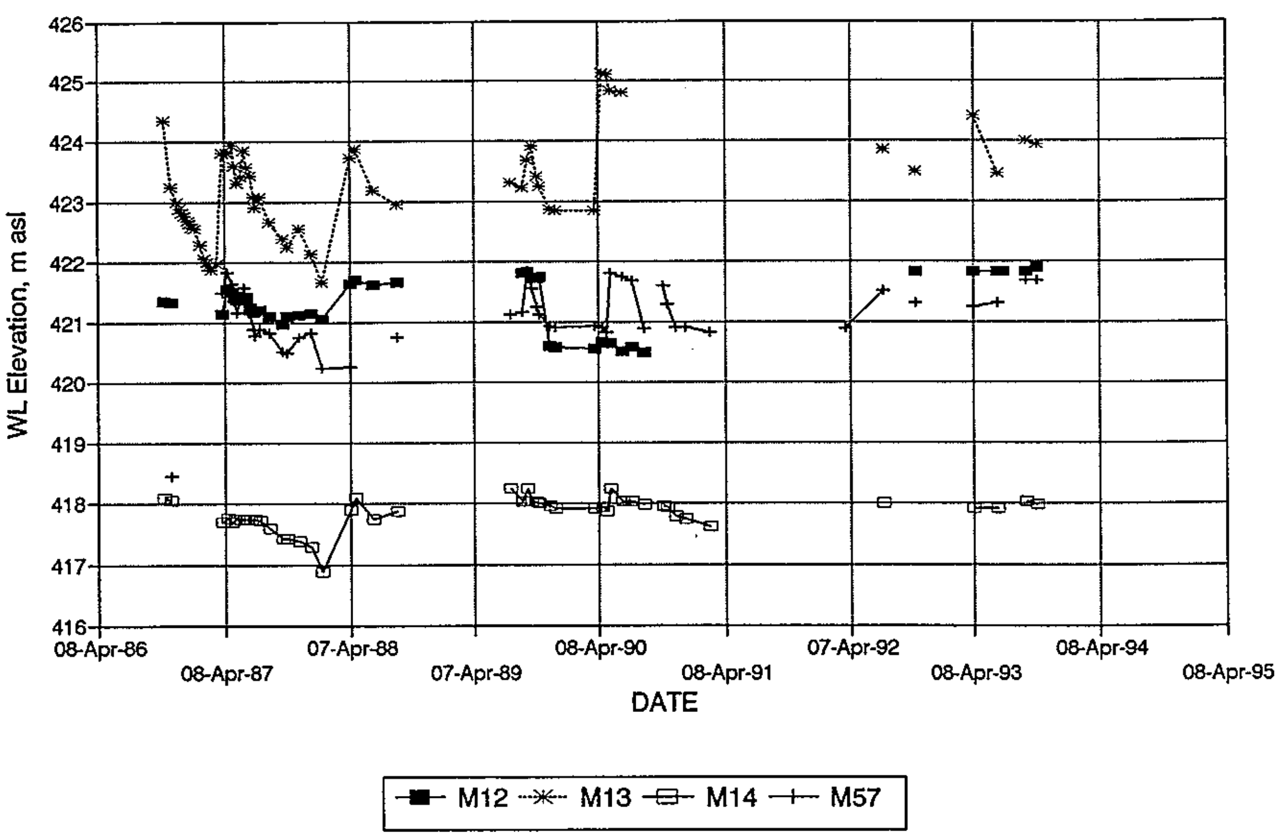


Fig. 8: Mine site water levels
M18, M38, PRC, BRC

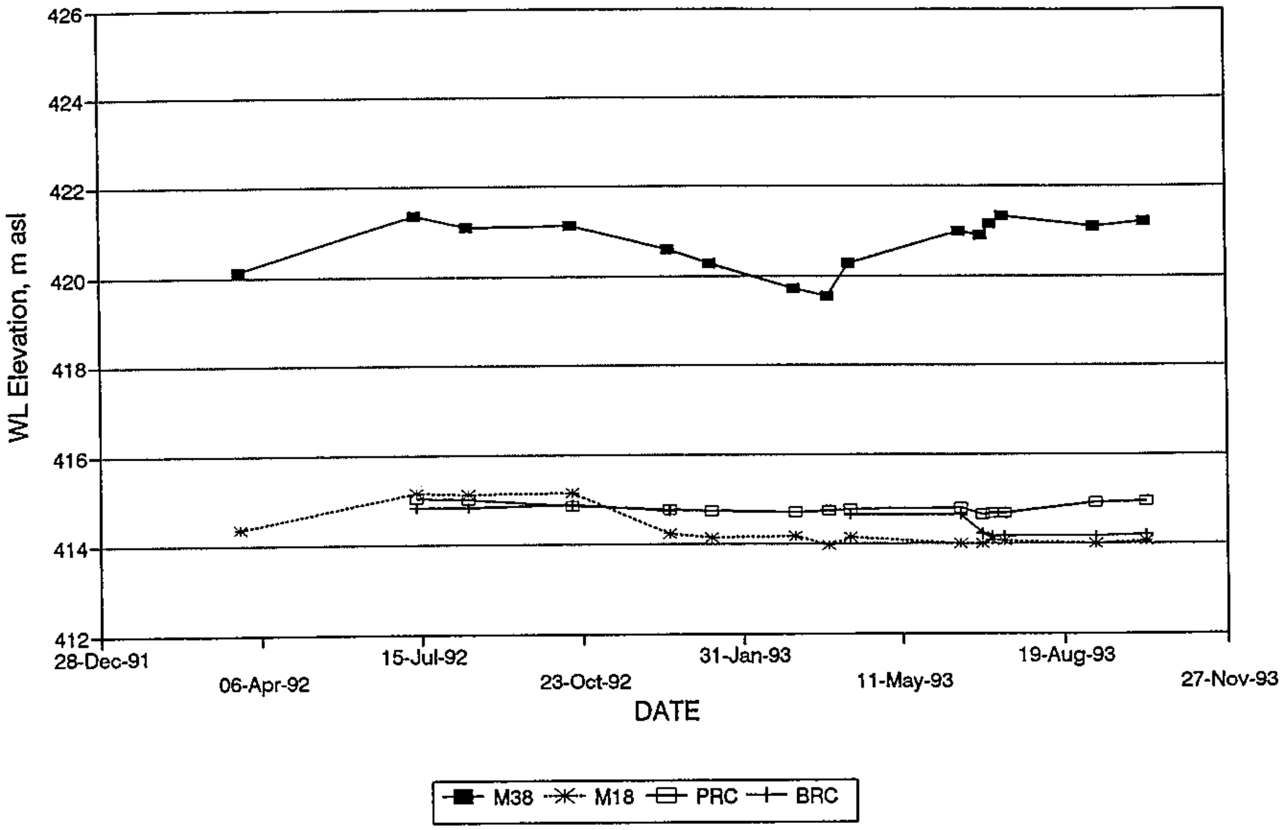


Fig. 9: Mine site water levels
M12, M13, M14, M57

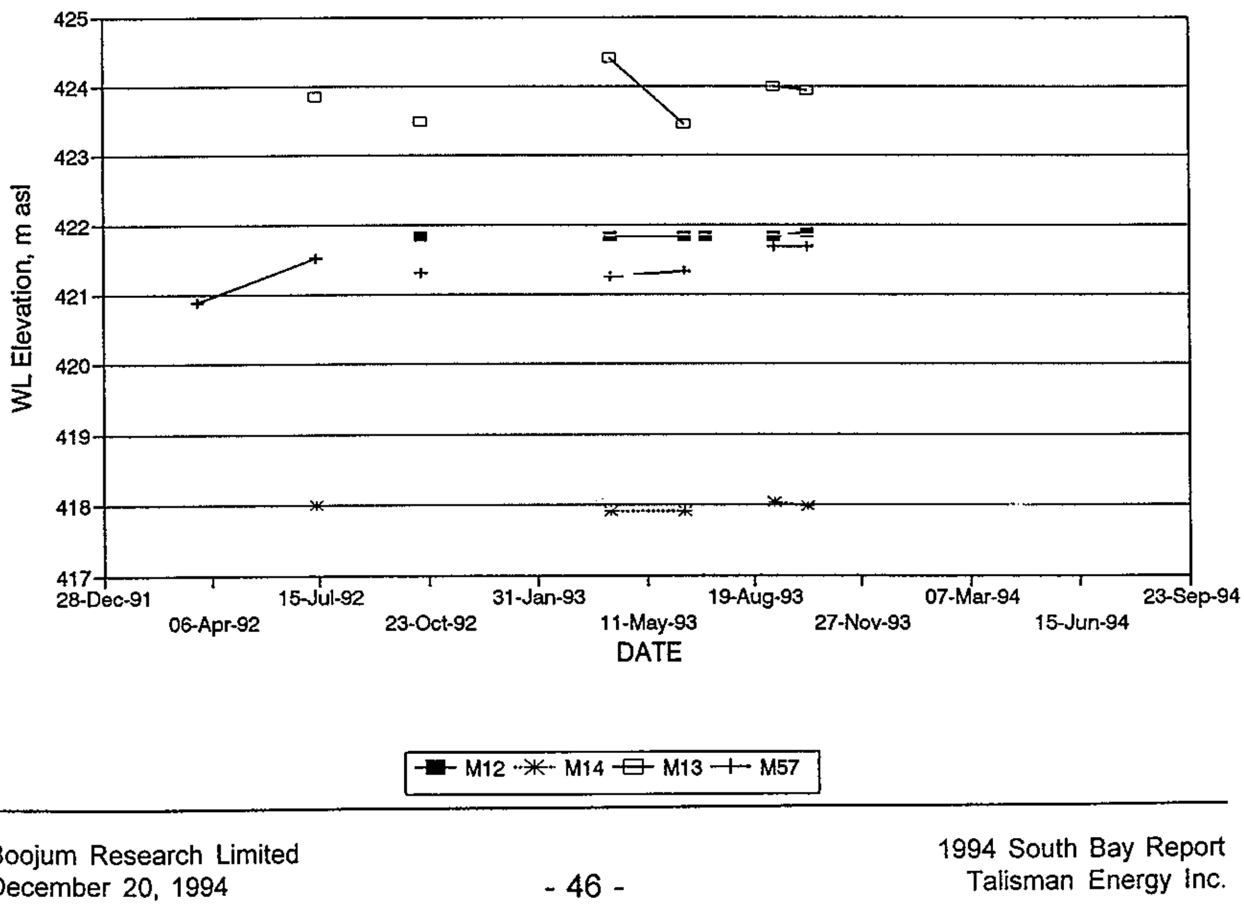


Fig. 10: Mine site water levels
PRC, BRC

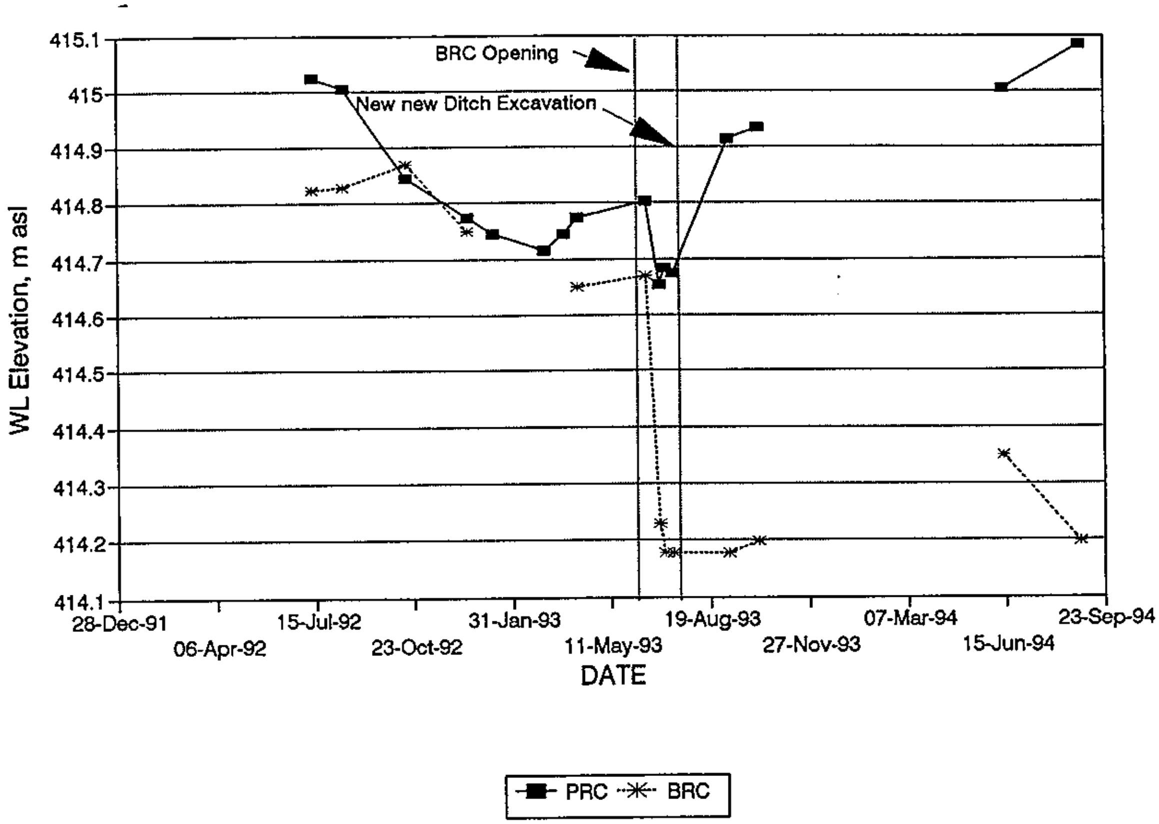


Fig. 11: Mine site water levels
BRC, M18

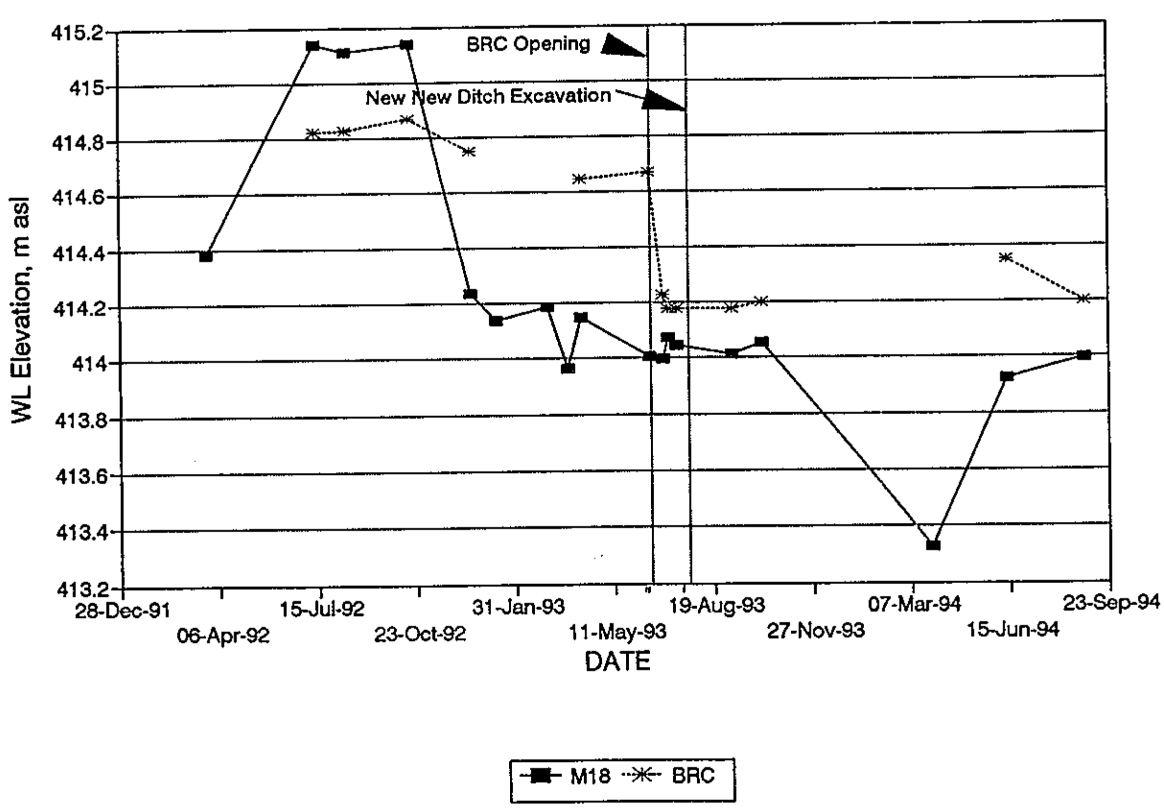
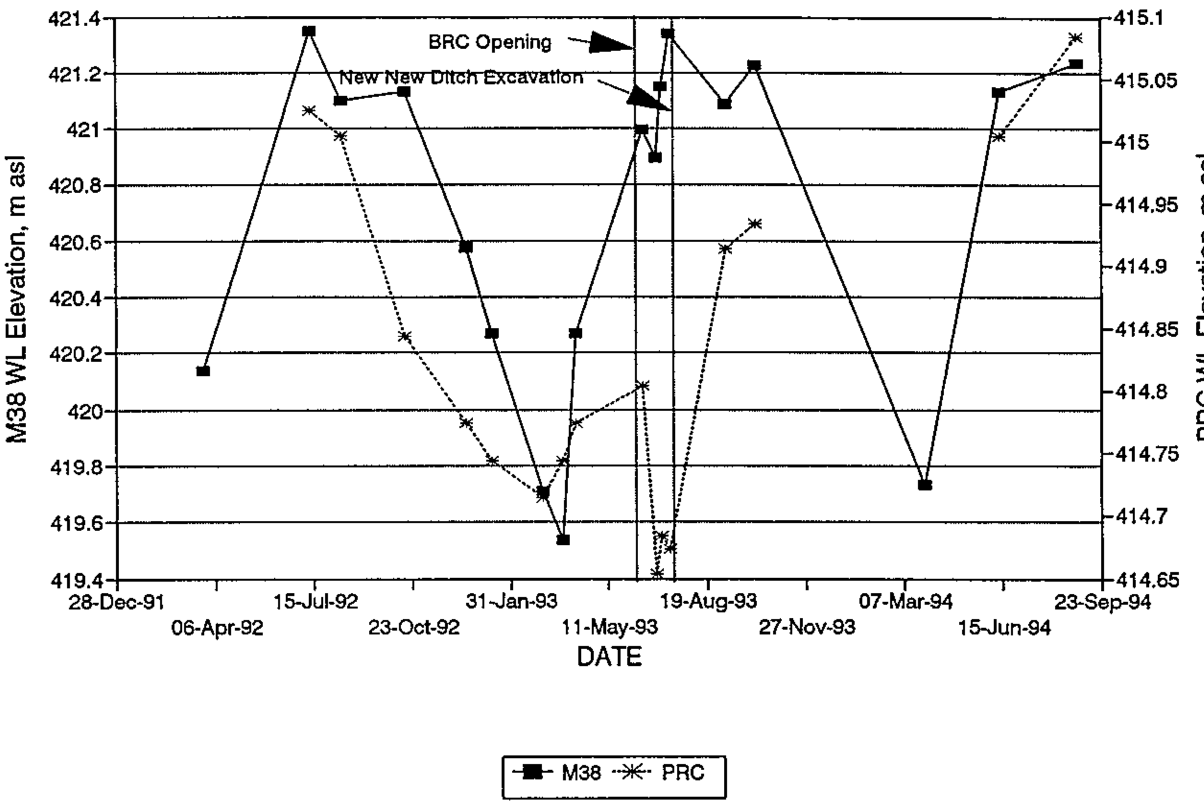


Fig. 12: Mine site water levels
PRC, M38



The water level inside BRC is undoubtedly influenced by the water level head in PRC. The PRC seepage, located further away from the Diversion Ditch, is governed to a significant degree by flows originating from Antenna Hill. Therefore, the overall effect of the Drainage Ditch on the Portal Raise area is the fact that the upper PRS seep stopped in April, but the lower seepages were still flowing in April and June with only a sight decrease in the flow rates. On the other hand, BR-13, affected directly by constructed ditch, was flowing at the rate of 0.14 L/s in April and stopped to flow in June.

Although the diversion ditch was effective in reducing the flow from BR13 seepage and from the PRS seepage, further actions were needed. An additional ditch was excavated to the elevation of PRS. All data, including those collected during the June l993 field trip, suggested that the BRC concrete structure should be opened to allow more water to drain from the underground workings into the ditch. This action would in turn eventually decrease the head in PRC.

The opening of the hole in the BRC, resulted in an instant drop in water elevation in BRC, and a decrease in water elevation in PRC followed (Figures 7). Furthermore, a new ditch (New New Ditch; also known as Ditch 2) was excavated to divert the water into the PRC from Antenna Hill. Observations on Ditch 2 during 1994 indicated that this ditch may not serve the expected purpose, as it collects too much clean water from Antenna Hill and creates a head to driving lower PRC seep.

3.7 Conclusions and Recommendations

The effectiveness of the ditches constructed on the mill/mine site in reducing surface loadings to Confederation Lake can be demonstrated by BR-13, which has ceased to flow. The assessment of the effects that the Diversion Ditch has on the groundwater flow regime, which drives the seepage at a depth of 6 m into Confederation Lake, requires a longer period of observation than is presently available. Some reduction in the groundwater seepage might be expected due to the absence of the peak water level noted during the spring in piezometer M18.

Based on data collected during and after the construction of the ditches, it is certain that the original Backfill Raise Ditch (Ditch 1) achieved its objective with respect to reducing the surface seepage at BR-13. However, that Ditch 2 is collecting water from Antenna Hill raises questions and uncertainties. Based on data collected in 1994, three potential scenarios are envisaged for Ditch 2:

- no physical action, but continued monitoring and on going assessment; or
- modify Ditch 2 by sealing the bottom and walls with plastic sheets, plugging the presumed (PRC) outflow, and redirecting the flow from Ditch 2 away from the waste rock fill which form the shoreline; or
- restore the site to pre-Ditch 2 conditions.

The conditions of Ditch 2 by the end of **1994** suggested that, depending on the effects of the **1995** spring run-off, either of the latter two options will have to be implemented.

Since excavation of the Backfill Raise Ditch (Ditch 1) in fall of **1992,** erosion of the embankments by run-off has resulted in a considerable amount of ditch infilling. After the **1994** spring-run off, from a visual assessment it was apparent that stabilization of the banks of the ditch was necessary, because the infilling had reached a point which inhibited flow into Boomerang Lake. This stabilisation was implemented in late summer **1994.**

4.0 HYDROLOGICAL CONDITIONS AND REMEDIAL MEASURES IN THE TAILINGS AREA

4.1 Re-evaluation of Hydrological Conditions

In 1986, a hydrological assessment of the tailings drainage basin established flow estimates in the different directions away from the basin. These are summarized in Table 10. Water levels were remeasured three times during 1993 in all piezometers, and hydraulic conductivities were re-determined in relevant piezometers. The 1993 estimates of groundwater discharge are given in Table 11.

When the 1993 calculations are compared to the 1988 estimates, the following differences can be noted:

- Hydraulic conductivity in the westerly direction has decreased, while an increase has been noted in the groundwater flows to the northwest.
- The southwesterly flow remained the same, although it had to be calculated using the H4-H3 gradient instead of H4-M23 (the saturated thickness and hydraulic conductivity remained unchanged).

Table 12 presents an estimated water balance for the Tailings Drainage Basin and the groundwater flow estimates for 1986-87 and 1993 (the easterly flow path towards Boomerang Lake was not re-evaluated).

In 1986 and 1987, surface water flows leaving Decant Pond were not available. The water balance was based on net run-off for flows in the different directions away from the tailings. A comparison of the total net run-off in the drainage basin with the data available for Decant Pond oufflow indicated that the flows within the tailings drainage basin are, to a large part, surface run-off. The groundwater flow estimations are based on calculated flow between pairs of piezometers and may not reflect the flow complexity which might exist within the tailings drainage basin.

Table 10: Estimated Groundwater Discharge from Tailings, 1986-1987 Average, after ROVE

Discharge direction	Hydraulic Cond.	Hydraulic Gradient	Saturated Thickness	Width of Zone	Daily Discharge	Flow Rate	Annual Discharge
	cm/s	m/m	m	m	m^3/day	L/s	m^3/a
1. West	2.0E-03	1.1E-02	7.3	297	39.4	NA	14,378
2. Southwest	2.0E-03	7.4E-03	14.3	122	22.4	NA	8,173
3. East	4.0E-04	1.0E-02	6.3	123	2.7	NA	977
4. Northwest	2.0E-03	1.0E-02	6.5	181	20.4	NA	7,437
5. North	1.0E-04	4.6E-03	2.5	152	0.2	NA	55

Total Discharge 82.3 m^3/d 30,043 m^3/a

Table 11: Estimated Water Discharge from Tailings, October 1993

Discharge direction	Hydraulic Cond.	Hydraulic Gradient	Saturated Thickness	Width of Zone	Daily Discharge	Flow Rate	Annual Discharge
	cm/s	m/m	m	m	m^3/day	L/s	m^3/a
1. West	1.0E-03	1.10E-02	7.3	300	20.9	NA	7,612
2. Southwest	2.0E-03	3.50E-03	14.3	150	13.0	NA	4,730
3. Northwest	3.0E-03	1.11E-02	6.5	200	37.4	NA	13,642
4. North	1.0E-04	3.62E-03	2.6	175	0.1	NA	52
5. Pond Outflow					142.6	1.65	52,034

Total Discharge 213.9 m^3/d 78,070 m^3/a

Table 12: Estimated Water Balance for Tailings Drainage Basin

Flow Direction	Area	Net Precip.	Total Net Run-off	Average Flow 86-87	Flow October 1993
	m^2	mm/a	m^3/a	m^3/a	m^3/a
1. West	32,000	250	8,000	14,378	7,612
2. Southwest	50,000	250	12,500	8,173	4,730
3. Northwest	32,000	250	8,000	7,437	13,642
4. North	11,000	250	2,750	55	52
5. To Decant Pond	80,000	250	20,000	977	
6. Fresh to Decant Pond	85,000	275	23,375		
7. Pond Precipitation	45,000	175	7,875		
8. Decant Pond Outflow					52,034
Total	335,000		82,500		78,070

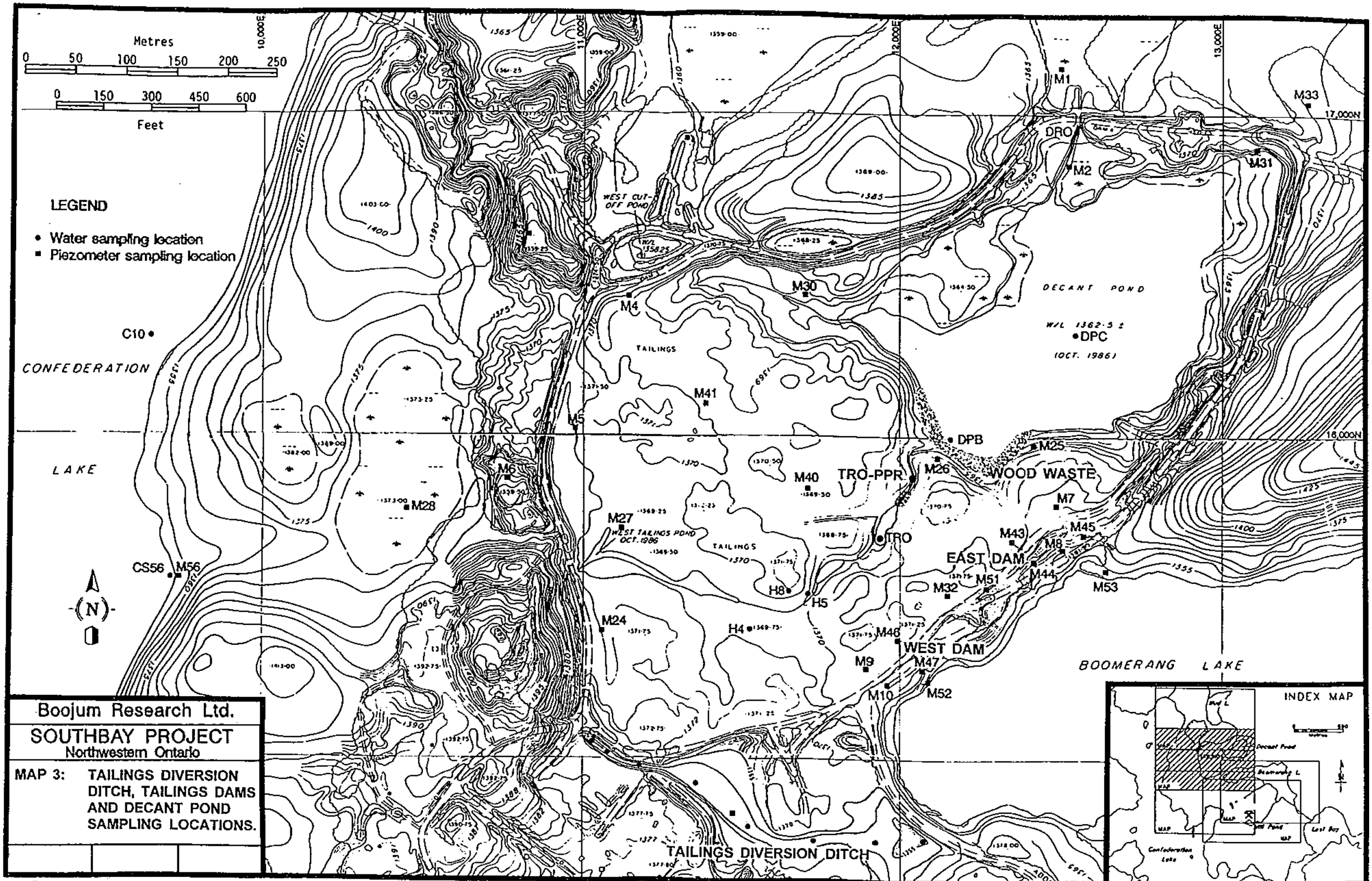
The re-evaluation of the hydrological conditions clearly suggests that Mud Lake receives, either by surface or groundwater, a large fraction of the water originating in tailings drainage basin. In addition, the volume of 8,000 m^3 of water per year that had been predicted to enter the Groundwater Diversion Ditch between the tailings and the townsite has been far less than expected. As well, the measured surface flow out of Decant Pond is much larger than had been anticipated.

From an elemental mass balance using piezometer water quality data (Kalin, van Everdingen and McCready, 1990), it was concluded that a large fraction of iron from pyrite dissolution may precipitate as a Na-jarosite in the tailings, thereby altering the permeability. This process is likely most prevalent in the southwesterly portion of the tailings deposit, as in this location, the tailings are mainly deposited as an unsaturated layer, and subject to seasonal water level fluctuations. This development is altering the flow directions and flow rates from the original assessment conducted in the late 1980s.

The reevaluation also indicated that Mud Lake should be receiving higher flows, and suggested that a water and sediment sampling program be carried out for the Mud Lake area in 1994. The data from the 1994 investigations on Mud Lake have been summarized in a separate report entitled: "The Mud Lake Report" dated November 25, 1994.

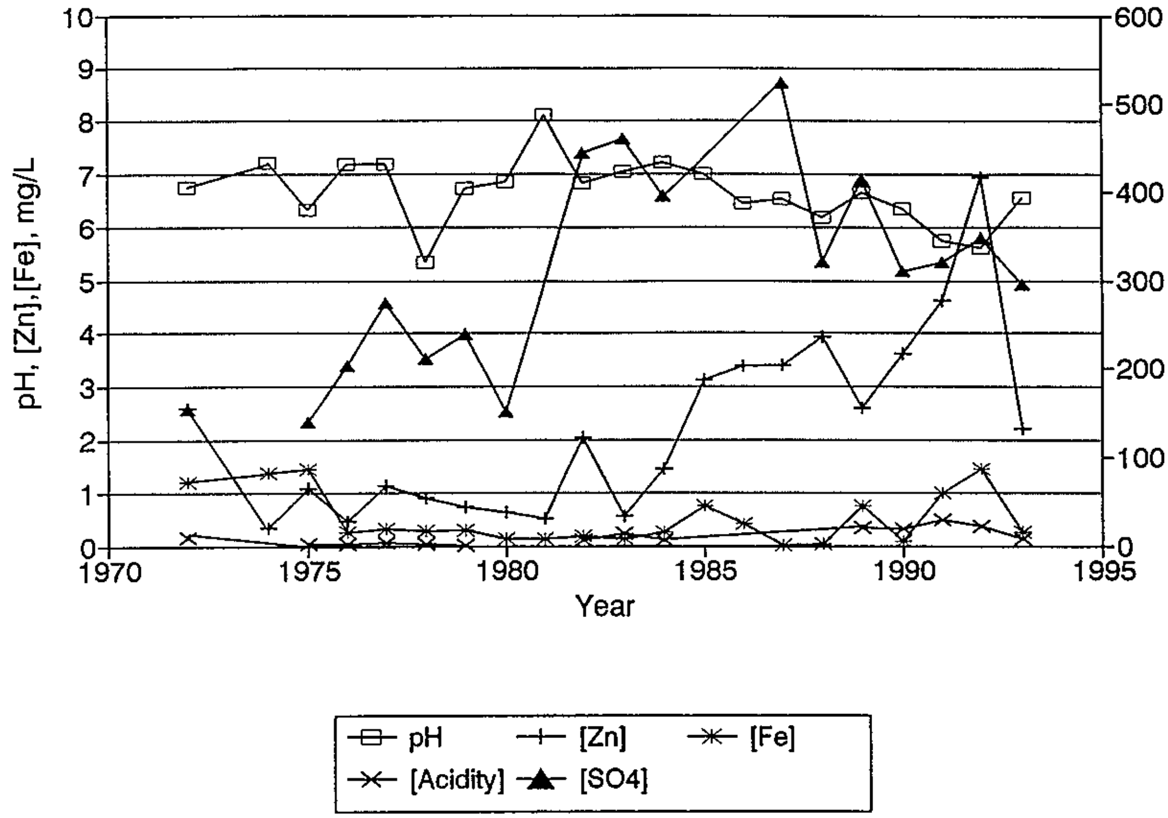
4.2 Remedial Measures - Tailings Run-off and Decant Pond

During operations from 1972 to 1982, the tailings area was filled with fresh, slurried tailings. Water, separated from the tailings solids, drained northward forming Decant Pond at the north-east end of the tailings. During the operations, the water chemistry of Decant Pond was determined by the water quality of the tailings supernatant and the lime which was added as required to Decant Pond. After mining ceased in 1982, the annual average pH at Decant Pond Ouflow (DRO; Map 3) remained above pH 5, and was typically around pH 7 (Fig. 13).



Metres
0 50 100 150 200 250
0 150 300 450 600
Feet
LEGEND
• Water sampling location
▪ Piezometer sampling location
10,000E
11,000E
12,000E
13,000E
17,000N
16,000N
CONFEDERATION
LAKE
BOOMERANG LAKE
WEST CUT-OFF POND
DECANT POND
W/L 1362·5 ±
(OCT. 1986)
TAILINGS
WEST TAILINGS POND OCT. 1986
WOOD WASTE
EAST DAM
WEST DAM
TAILINGS DIVERSION DITCH
TRO-PPR
TRO
DPB
DPC
DRO
C10
CS56
M1
M2
M4
M5
M6
M7
M8
M9
M10
M24
M25
M26
M27
M28
M30
M31
M32
M33
M40
M41
M43
M44
M45
M46
M47
M51
M52
M53
M56
H4
H5
H8
INDEX MAP
Boojum Research Ltd.
SOUTHBAY PROJECT
Northwestern Ontario
MAP 3: TAILINGS DIVERSION DITCH, TAILINGS DAMS AND DECANT POND SAMPLING LOCATIONS.

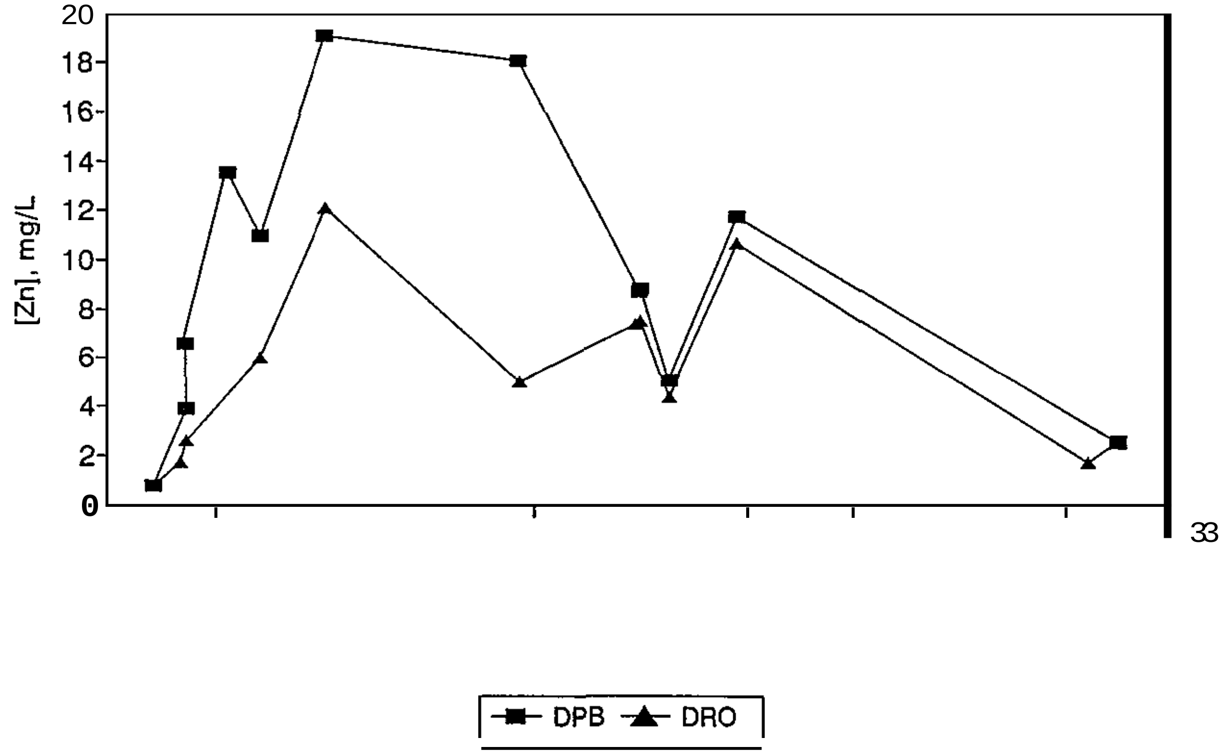
Fig. 13: Decant Pond Outflow Annual Avg
pH,[Zn],[Fe],[Acidity] and [Sulphate]



Annual average zinc and iron concentrations remained below 2 mg/L, while sulphate concentrations ranged between 100 and 300 mg/L (Fig. 13). Since mine shutdown, water leaving Decant Pond has been comprised of fresh water run-off from the north eastern part of the drainage basin and acidic drainage from the tailings area. In addition, some fresh and/or acidic groundwater may be entering Decant Pond from the east and/or south-west, respectively. Liming of Decant Pond stopped by l986.

The average pH of water leaving at Decant Pond Outflow has remained above pH 5, although there is some suggestion of a downward trend between 1984 and 1992 (Fig. 13). The annual average pH at Decant Pond Outflow increased again in 1993, relative to 1991 and 1992. The annual average zinc concentration at Decant Pond Outflow steadily increased between 1983 and 1992 reaching as high as 7 mg/L (Figure 13). In Figure 14, the differences in zinc concentrations at the Decant Pond beach sampling station and the outflow are presented.

Fig.14: Decant Pond Beach and Run-off
Zinc Concentrations



It is evident that the zinc concentrations at the Decant Pond beach increased steadily in l991 and zinc was removed significantly in the pond by biological polishing by the time the water reached the ouflow. The reduction in pH resulted in diminishing the algal population on the beach, which were previously effectively removing zinc at a circumneutral pH range.

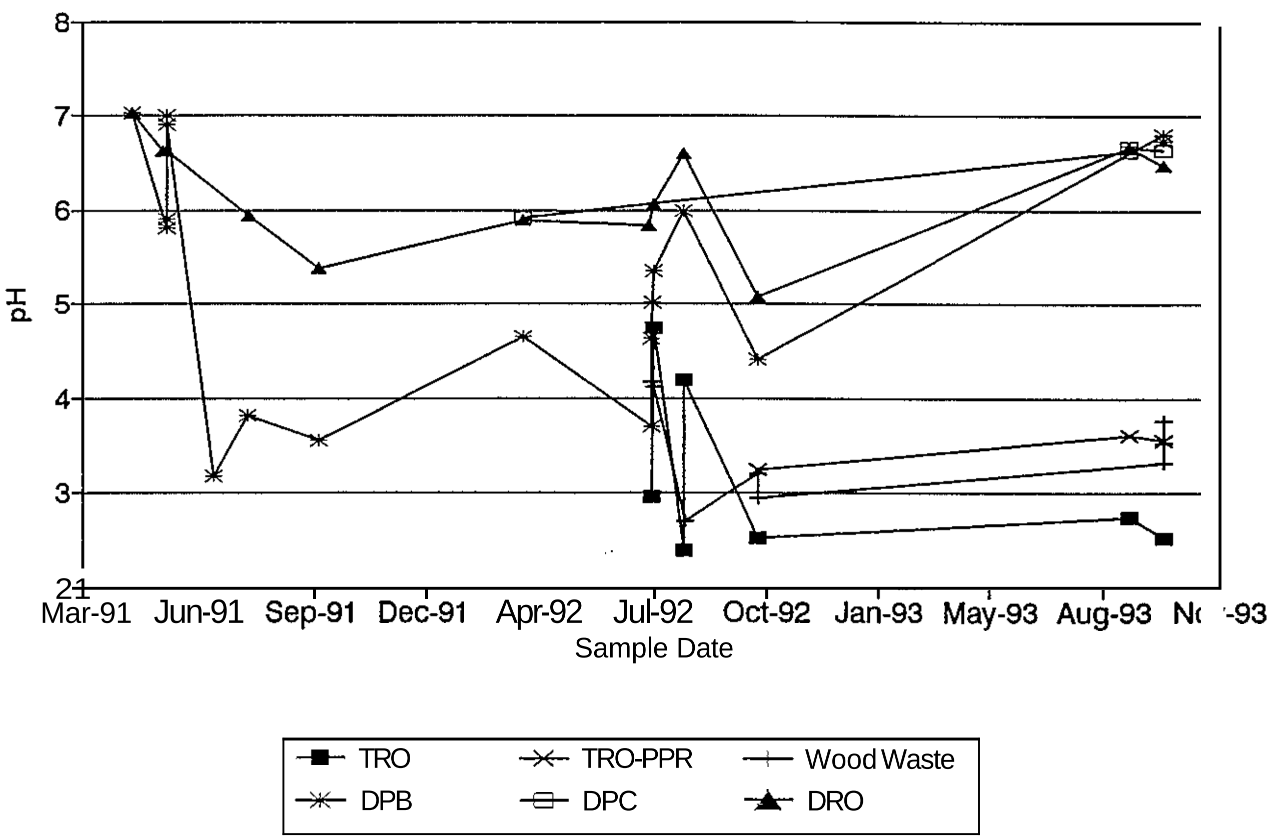
In 1992, remedial measures were taken in the tailings run-off and Decant Pond beach areas in order to reduce acidity and metal loadings to Decant Pond. These measures included distribution of natural phosphate rock (TRO-PPR) over the stream path of acidic drainage from the tailings (TRO), and the distribution of partially decayed wood slabs (wood waste) along the beach of Decant Pond. The locations are given in Map 3.

These remedial measures may well be responsible for the higher average pH in Decant Pond and lower zinc concentrations observed at Decant Pond Ouflow in 1993 compared to the previous two years. The average zinc concentration was only

2.2 mg/L in 1993 compared to 7 mg/L in 1992. Similarly, iron and acidity were lower in 1993, compared to 1991 and 1992 (Figure 13).

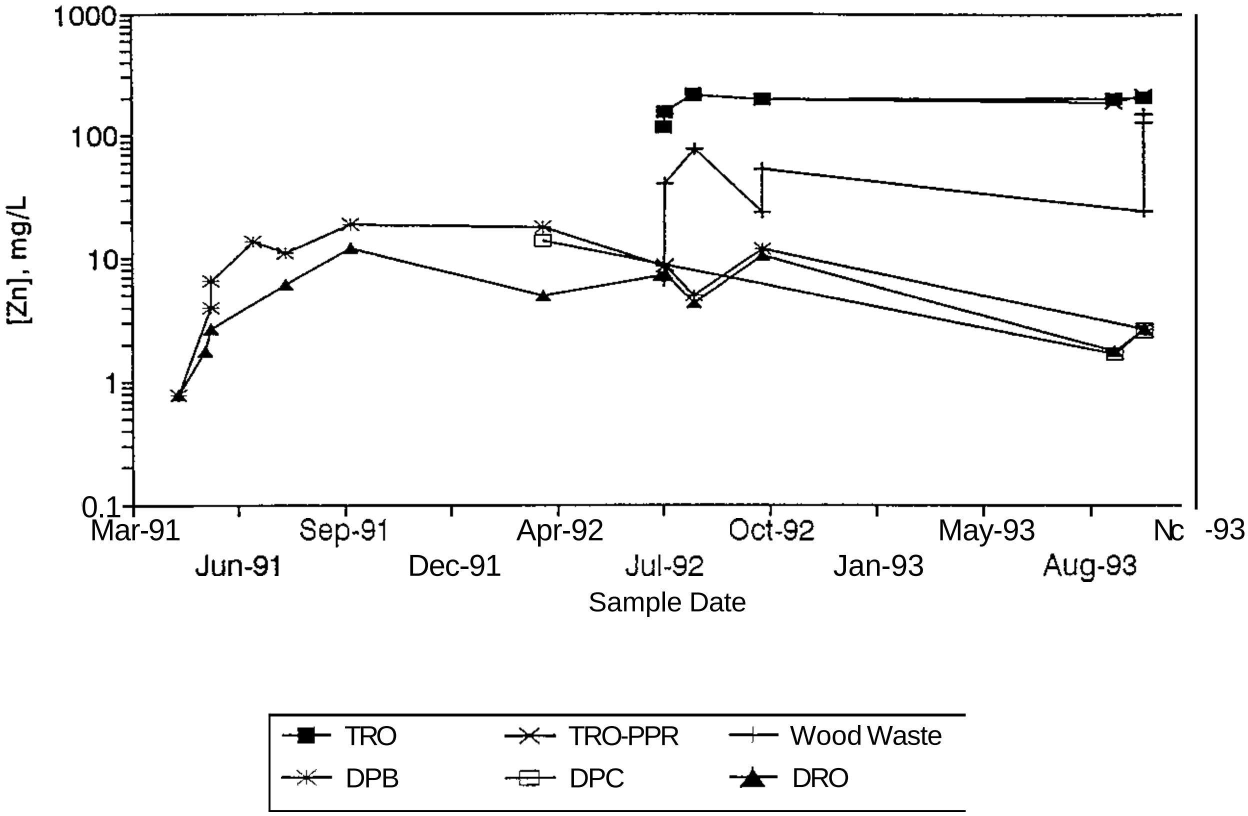
In Figure 15, the pH of individual water samples collected between 1991 and 1993 from the tailings run-off (TRO), the tailings run-off after passing over phosphate rock (TRO-PPR), in the wood waste zone (Wood Waste), and along Decant Pond Beach (DPB), centre (DPC) and outflow (DRO) are presented. The TRO station was not sampled before 1992, as there was no ponding water in this location previously. However, because of especially high rainfall in the years 1992 and 1993 water ponded and resulted in the depressed pHs along the Decant Pond Beach **(July,** 1992). A pH as low as 3.2 was measured at DPB in June 1991 and it recovered only slightly during the summer months and the beginning of 1992. After the remedial measures, a very rapid increase in pH was noted from 3.7 to 6 by then end of the summer. The effects of the phosphate rock placement in the TRO run-off is still evident at the end of 1993, elevating the pH from 2.5 to 3.5.

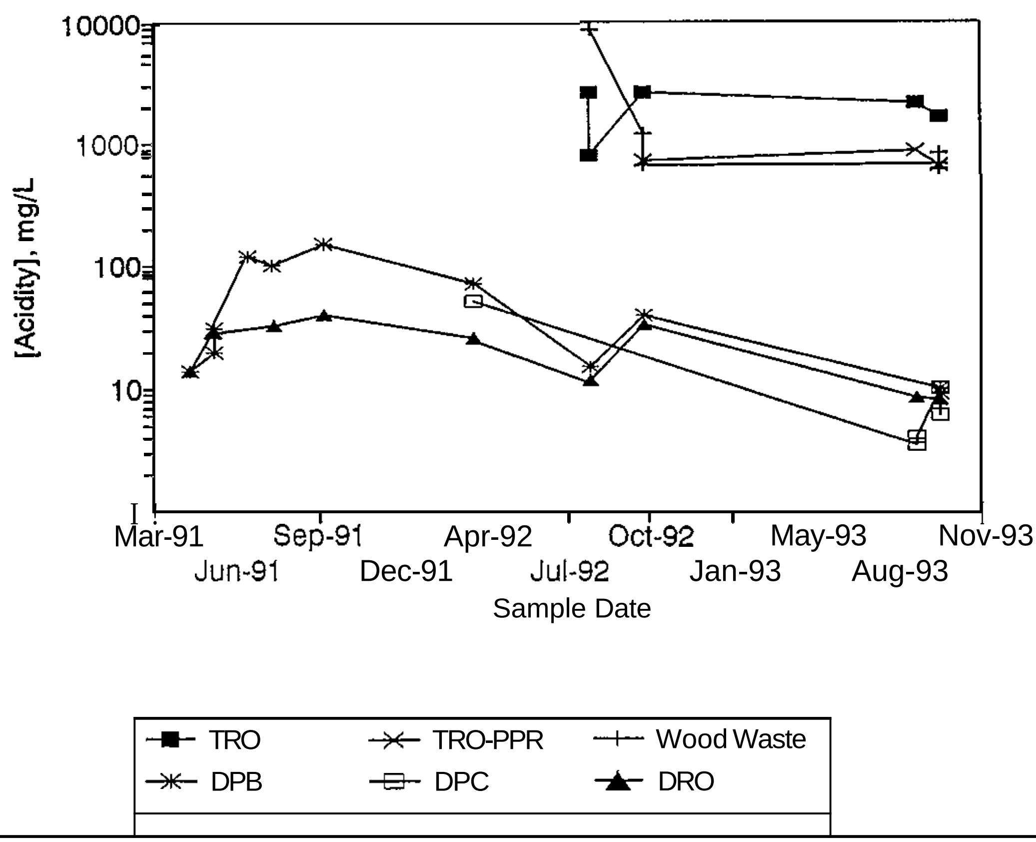
Fig.15:Tailings Run-off-Decant Pond pH
TRO, TRO-PPR, DPB, DPC, DRO



Following application of phosphate rock and wood waste along Decant Pond beach, the pH's of the new Decant Pond beach, centre and ouflow became higher (Fig. 15). The zinc concentrations (Fig. 16) and acidity (Fig. 17) have both decreased (note log scale) from the period prior to phosphate rock and wood waste placement. Overall, there is evidence that these remedial actions are serving the objective to counteract the acidification of Decant Pond due to the TRO and the acid generation on the tailings beach. Zinc concentrations in Decant Pond ouflow were further reduced to 1.0 mg/L throughout 1994.

Fig.16:Tailings Run-off-Decant Pond Zn
TRO, TRO-PPR, DPB, DPC, DRO





5.0 BOOMERANG LAKE - THE CONTAMINANT SINK

Boomerang Lake has been designated to operate as the final treatment zone for run-off from the mill area and tailings. Contaminant removal processes in Boomerang Lake include biological polishing of metals by attached algae, co-precipitation of zinc with ferric hydroxide and sulphate removal from water by sediments.

Up to 1992, contaminant loadings to Boomerang Lake were estimated and the removal capacity of both Biological Polishing by algae growing on brush, and ARUM capacity in the sediment, were estimated based on work in other sites. However, the growth rates of algae and the sediment ARUM capacity were, however, quantified during the same period when conditions of Boomerang Lake were slowly but steadily deteriorating.

A critical deterioration threshold for AMD systems is when the AMD reaches pH 3.0 **as,** below that pH, ferric iron stays in solution. Quantification of the iron precipitation rate, which is an important component *of* zinc removal processes, suggested a large difference between the amount of iron which was collecting in sedimentation traps and the amount that was expected based on annual loadings to Boomerang Lake.

These findings, along with recommendations, were reported in 1993 to the Ministry of Environment and Energy. In 1993, the recommendations were implemented and further additions of phosphate rock were made to the lake to remove iron. As well, efforts were made to further quantify the sedimentation rates. These results are described in a separate report entitled : Biological Polishing Phase IV: Model Verification and Scale-up. CANMET Contract, July 1994.

The contaminant loadings to the lake have to be quantified in order to assess the capacity of the contaminant removal processes which operate in the lake. The available data are used to quantify the loadings of key contaminants from the different parts of the drainage basin to Boomerang Lake.

Boomerang Lake receives, in addition to direct precipitation onto the lake, clean run-off from its north and east sides of the drainage basin. Contaminated water arrives from the following drainage basin parts:

a) Mill Pond through Mill pond run-off.

b) Underground mine water and contaminated run-off from the mine site draining through the Backfill Raise diversion ditch.

c) Drainage from the groundwater diversion ditch between the tailings and the townsite. A polishing pond is integrated into this ditch prior to entry to Boomerang Lake.

d) Seepage from the base of the west and east tailings dams.

Some drainage from the Mill pond area, and seepage from the East and West Tailings Dams, has always entered Boomerang Lake since the operation of the mill began and the construction of the dams. Two drainage ditches, the tailings groundwater diversion ditch and the Backfill Raise ditch, were excavated since shutdown, and were designed such that groundwater does not migrate to Confederation Lake, but is intercepted and reports to Boomerang Lake as overland flow (Map 2 and Map 3).

The tailings groundwater diversion ditch was excavated in May, 1987 along the tailings-townsite interface. The excavation of the Backfill Raise ditch was completed in January 1993. The areas where seepages flow through the west and east tailings dam were grouted in 1986 at the time of the hydrological investigation.

Changing the drainage basin configuration such that contaminants arrive in surface water rather than in groundwater does not necessarily change the volume of water, but changes the chemical characteristics of the water. Contaminants in groundwater, emerging to to join surface water flow, can be precipitated in the diversion ditches due to changes in oxidation state, depending on the pH and the prevailing iron and alumnium oxidation reactions.

Long-term water quality data, combined with estimates of run-off from various areas, are required in order to differentiate the various processes which are contributing contaminants to, or removing contaminants from, the Mill area and tailings run-off as it travels towards and joins Boomerang Lake's volume.

The water quality data are summarized in the following section for Boomerang Lake, Mill Pond, the two diversion ditches constructed in Backfill Raise and the tailings area, along with the seepages from the east and west tailings dams.

5.1 Long Term Contaminant Trends in Boomerang Lake

5.1.1 Boomerang Lake

Water samples have been regularly collected in Boomerang Lake each year since 1971. The pH, as well as dissolved iron, zinc, acidity and sulphate concentrations were typically determined in these samples. Water samples have been collected from a variety of locations in these years, including sampling locations B1, close to the ouflow of the lake, and B13, close to the tailings dam. However, since samples were typically collected during the ice-free season, and Boomerang Lake is completely mixed during the summer, all surface water data were averaged for the year. The annual average values for these parameters between 1971 and 1993 are shown in Figure 18a and 18b.

Fig. 18a: Boomerang Lake Annual Average
pH, [Zn] and [Fe]

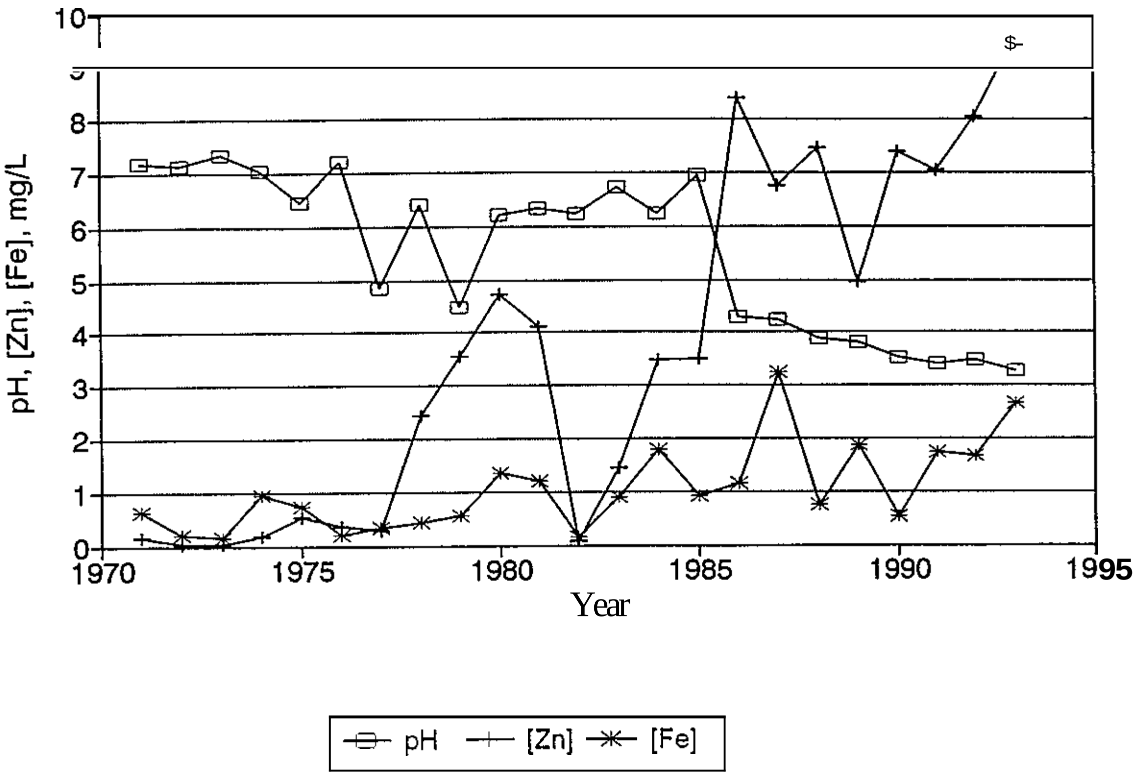
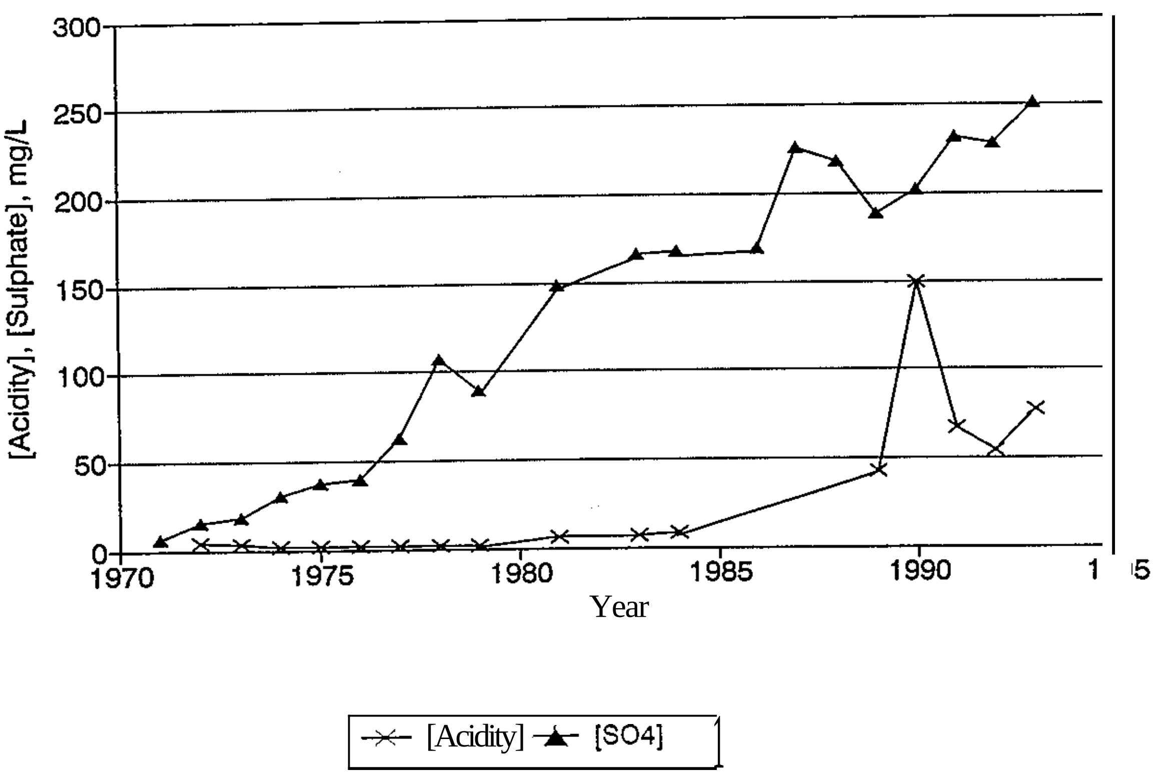


Fig. 18b: Boomerang Lake Annual Average
[Acidity] and [Sulphate]



Decreases in pH and increases in concentrations of iron, zinc, sulphate and acidity in Boomerang Lake between 1971 and 1993 are the result of input of contaminants from sources including the mill and tailings area. These changes are evident in Figure 18a and 18b. During these years, changes in contaminant loadings were offset to some degree by dilution by clean run-off, neutralization and precipitation by lime additions, and by physical/biological processes in Boomerang Lake's water and sediment.

The annual average pH of Boomerang Lake was above 7 between 1971 and 1974, typical for a natural lake in this region. However, the pH was variable and overall lower from 1975 to 1979. The annual average pH was relatively constant between 6 and 7 between 1980 and 1985, probably due to lime addition in Mill Pond, **but** suddenly dropped in 1986 to pH 4.3. The annual average pH has been steadily declining in the years since. The 1993, the average pH was 3.26.

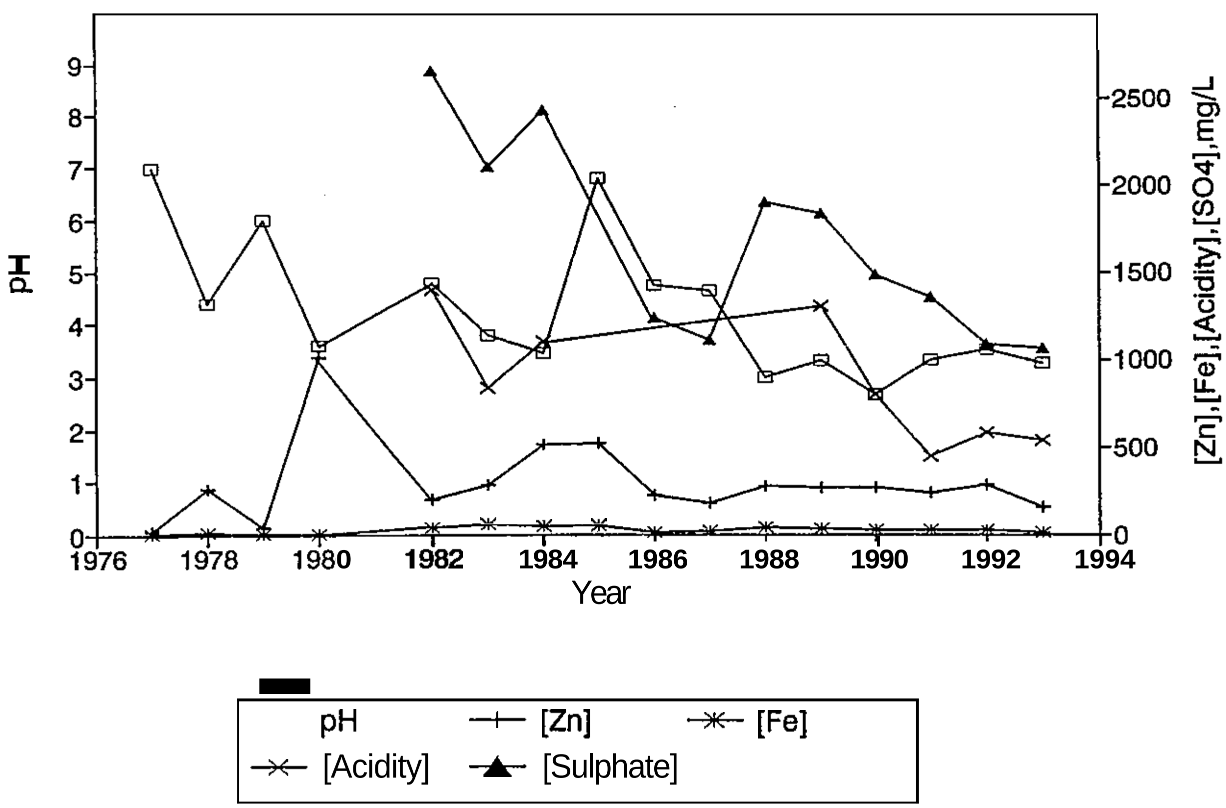
In 1971 to 1977, zinc concentrations remained lower than 1 mg/L. However, zinc concentrations rapidly increased between 1978 and 1981 to higher than 4 mg/L. Zinc concentrations were variable between 1982 and 1985, likely due to the effects of lime addition in the drainage basin. In 1986, zinc concentrations increased to greater than 8 mg/L on average. Zinc concentrations again declined in 1987 and 1989 to 7 and 5 mg/L respectively. The absence of further increases was attributed to the biological polishing capacity which was slowly increased during these years. However, annual average zinc concentrations have been increasing again since 1990, and the average 1993 zinc concentration was 9.5 mg/L. This is likely due to the further reduction in pH and the increase in acidity, which impairs algal growth.

Annual average iron concentrations have, overall, been increasing since 1971 (0.63 mg/L), and averaged 2.66 mg/L in 1993. However, overall iron concentrations have remained low, since ferric iron's solubility is low at pH values greater the 3.0 to 3.5. In contrast, the sulphate concentration in Boomerang Lake has steeply increased between 1971 (5.8 mg/L) and 1993 (251 mg/L; Figure 18b).

Although only a few acidity determinations were taken prior to 1989, it appears that Boomerang Lake's acidity remained below 10 mg/L CaCO, equivalent. However, in 1989, Boomerang Lake's acidity was 43 mg/L CaCO, equiv. (n=1), and in 1993, the average acidity was 80 mg/L CaCO, equiv.

5.1.2 Mill Pond Ouflow

Mill Pond is a shallow area adjacent to former mill and shaft sites on the mine site. This pond overflows in spring and fall, but does not typically discharge surface water during dry summer periods and winter.



The elevated contaminant concentrations in this pond are due to drainage of contaminated water from the ore stockpile and mill areas. Given the proximity of the pond to the shaft area, additional contaminant loading from mine workings groundwater emerging from Mill Pond bottom, along with loadings from the waste rock pile, cannot be ruled out.

Annual average zinc, iron, acidity and sulphate concentrations were higher in the years 1982 to 1991, compared to 1992 and 1993. This trend of decreasing concentrations suggests that the measures implemented in Mill Pond (sawdust for adsorption, straw to establish ARUM active sediment and assist algal growth) may at least in part reduce the contaminant supply in addition to a general reduction in the loading from the re-contoured Mill site. However, at present, the remaining relatively high zinc concentration represents a major supply to Boomerang Lake. Therefore, in the Mill Pond run-off area, three retention dams have been installed with biological polishing capacity.

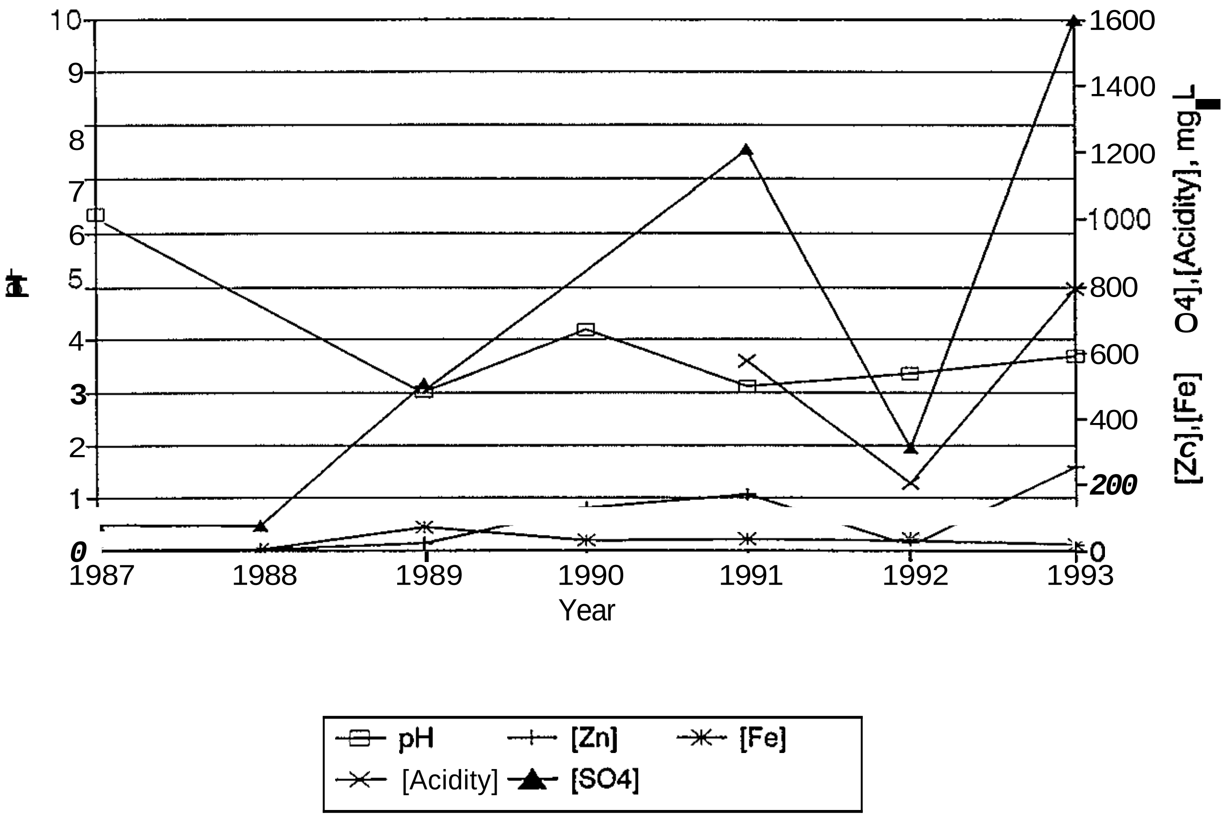
5.1.3 Backfill Raise Area

The Backfill Raise area is comprised of a natural depression between the Mill site and the hill to the northwest, extending from the tailings access road eastward down to Boomerang Lake. The Backfill Raise Area came about its name, since a raise was driven in this area for delivery of backfill material the underground. Acid mine drainage was observed to collect in this area in 1985, presumed to originate from the tailings spill to the north. During demolishing of the mill building and the re-contouring of the site in 1987, the depression with acid mine drainage was treated with lime and filled in. The flow direction of the drainage basin was diverted, as a slight head of fresh water was driving some freshwater towards the old Backfill Raise pond.

In late 1991 and 1992, acidic seepages containing elevated zinc and iron concentrations were observed very near (PRS) or entering (BR13) Confederation

Lake along the shoreline west of the Backfill Raise area. Due to the heavy rainfall in these years, the groundwater level in the Mill area was elevated. Also, seepage from the raise joined with the underground workings could have been expected. Therefore, a deep ditch was excavated in the fall of 1992, from the road eastward to Boomerang Lake, in order to lower water levels in the Backfill Raise area and to divert the groundwater supplying the BR13 and PRS seepages away from Confederation Lake.

Fig. 20: Backfill Raise Annual Average pH, [Zn],[Fe],[Acidity] and [Sulphate]



Water sampling has been periodically performed since 1987, when the ditch was lowered only slightly to improve flow along the fault line towards Boomerang Lake. These represented sampling stations BR2.5, BR3, BR3.5 and BR4, which have been eliminated due to the construction of the deeper ditch in 1992 (Map 2). Flowing water was usually available for sampling at these stations. Only a few samples were taken each year (1989, 1990) as the water quality was generally acceptable (Figure 20).

Long-term trends in pH and zinc, iron, acidity and sulphate concentrations clearly evident in Figure 20. Since the construction of the deeper ditch in 1992, pronounced contaminant concentration increases are apparent, particularly for sulphate.

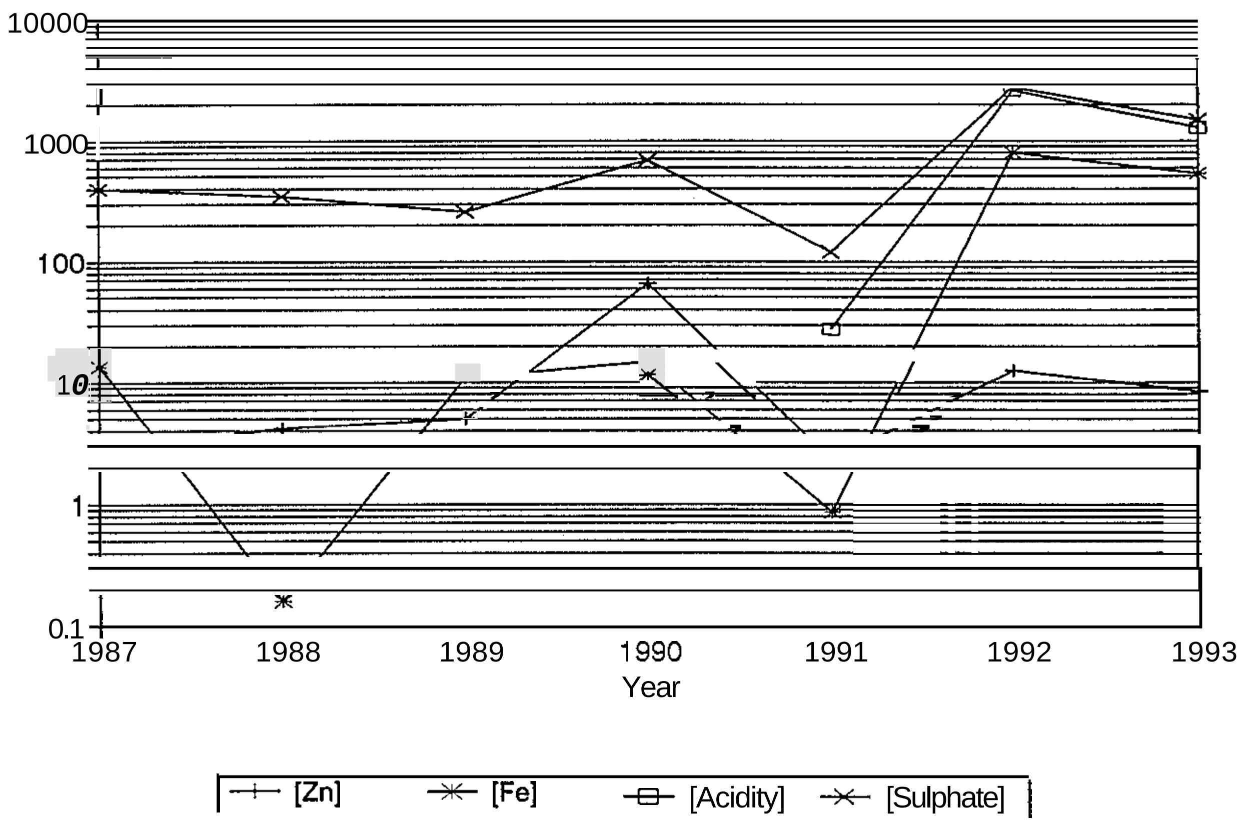
5.1.4 Tailings Groundwater Diversion Ditch

The monitoring data from piezometers in the tailings and town site area suggested that tailings groundwater was migrating beneath the townsite towards Confederation Lake. In response, a ditch was excavated in May, 1987, along the interface between the tailings and townsite, such that intercepted groundwater could travel overland towards a collection pond adjacent to Boomerang Lake.

The pH of samples collected from the ditch and the collection pond between 1987 and 1991 were greater than 4.5, while the pH of samples collected in 1992 and 1993 were much lower, at pH 3.4 and 3.1, respectively (Figure 21a). Similarly, the 1987 through 1991 samples contained much lower concentrations of iron (0.16 to 14.8 mg/L). The concentrations of sulphate (119 to 686 mg/L), compared to the 1992 and 1993 iron concentrations (526 to 804 mg/L) and acidity concentrations (1472 to 2785 mg/L) have also increased (Figure 21b). Clearly, the groundwater collected by the diversion ditch in 1992 and 1993 contained much higher contaminant concentrations than in the previous years. These changes where part of the reason to conduct the electromagnetic survey, discussed in Section 3.4.

Fig. 21a: Tailings Div. Ditch Annual Avg
pH

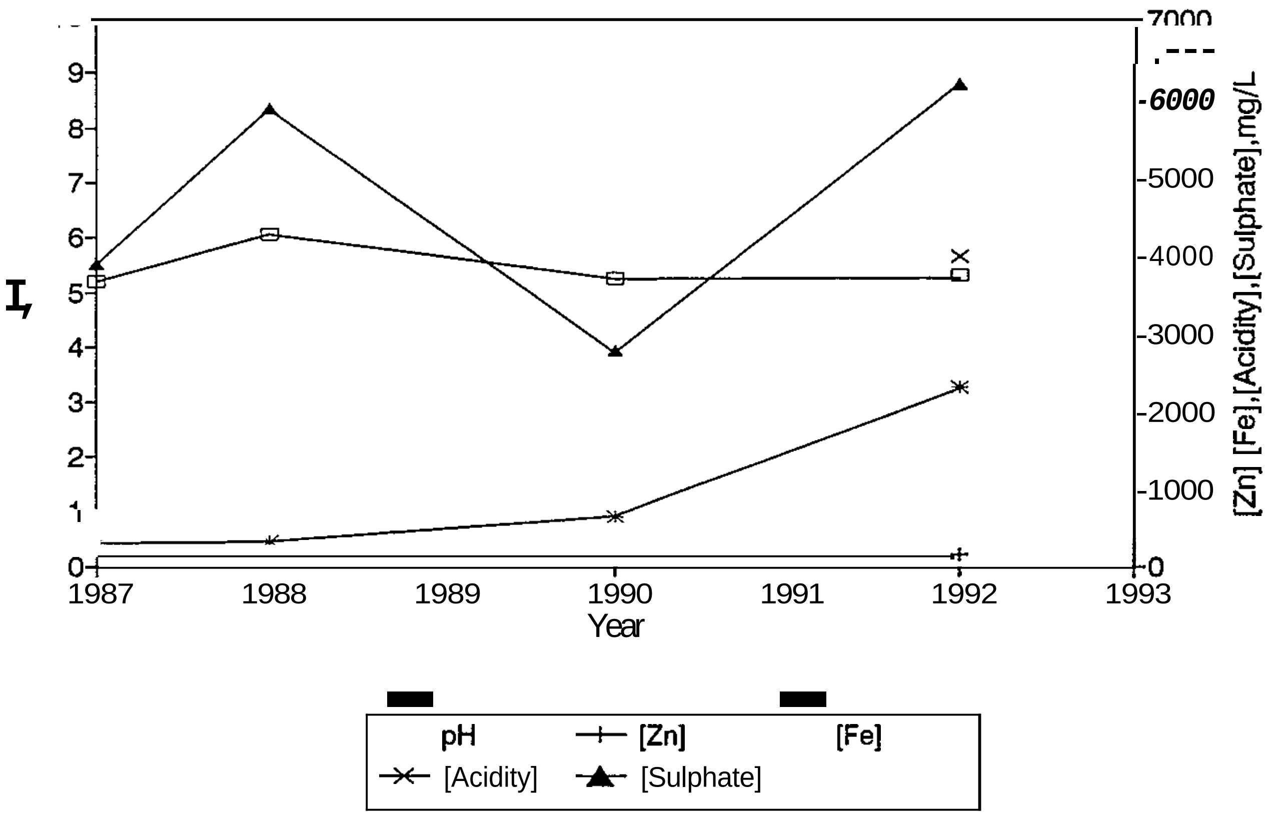
Fig. 21b: Tailings Div. Ditch Annual Avg
[Zn], [Fe], [Acidity] and [Sulphate]



5.1.5 West Dam Piezometer M47

Piezometer M47 is situated below the west tailings dam adjacent to Boomerang Lake. Water quality monitoring data for this piezometer in the years 1987, 1988, 1990 and 1992 indicate was groundwater sampled by this piezometer contains high concentrations of zinc (73 to 219 mg/L), iron, 290 to 2300 mg/L) and sulphate (2742 to 6180 mg/L), Figure 22. The acidity measured in 1992 was 3975 mg/L $CaCO_3$ equiv. Since the pH upon collection is typically 5.2 and higher, iron dissolved in this groundwater is the ferrous oxidation state.

Fig. 22: West Dam M47 Annual Average
pH, [Zn],[Fe],[Acidity] and [Sulphate]



Since this piezometer is located between the dam and Boomerang Lake, the dam must be leaking, and groundwater with the above characteristics is entering Boomerang Lake. While no surface seepages are obviously flowing in this region, upon addition of phosphate rock along this shoreline, precipitates formed and streamed out from the shoreline just below the water level.

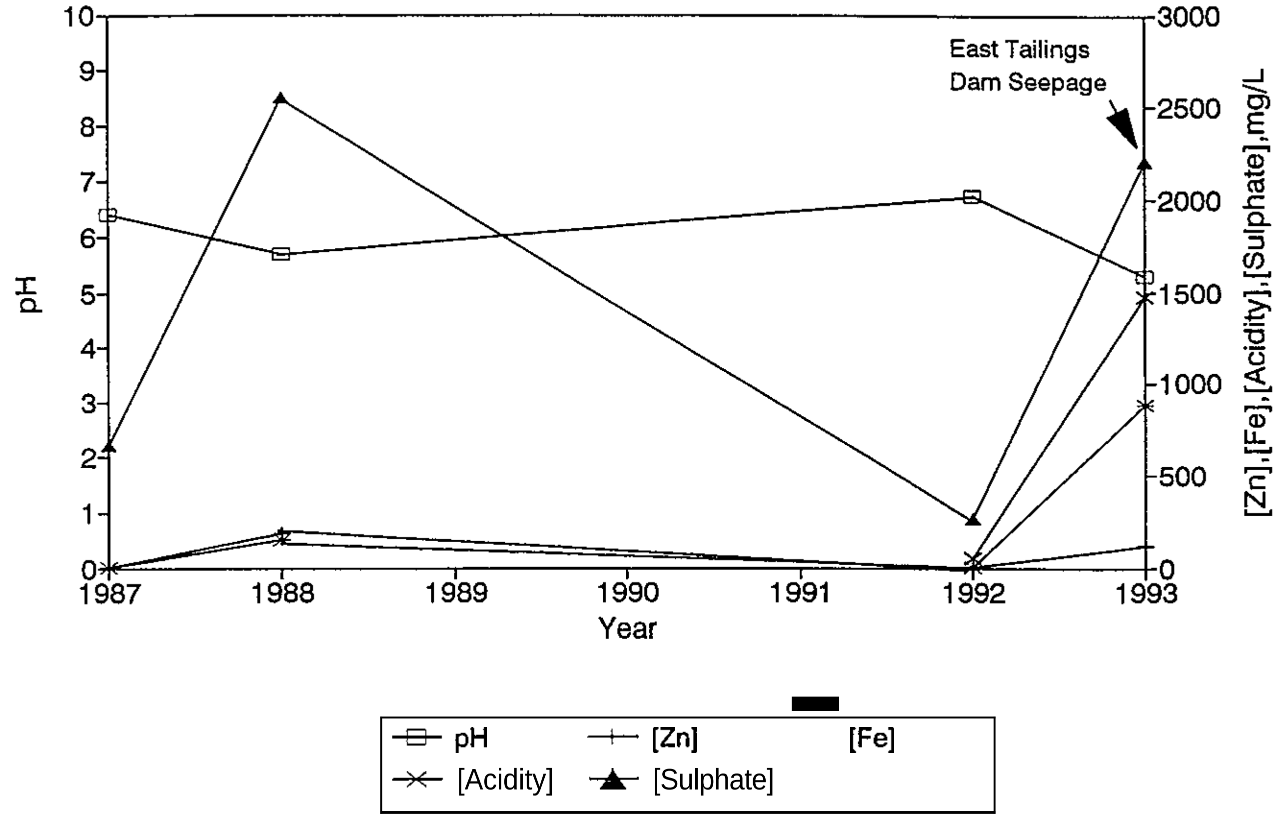
The phosphate rock applications carried out in **1992** and **1993** concentrated specifically on these seepage areas. At the outset of the project, and after the grouting, brush was placed in the seepage areas, and prolific algal growth was quantified. In the last two years, algal growth has ceased in these areas. This is a certain indicator that seepage is entering the lake at a higher rate than in previous years. Algae do not grow in water where iron is oxidizing (Kalin and Wheeler **1992).**

5.1.6 East Dam Seepage and Piezometers M8 and **M44**

Seepage of tailings groundwater is entering Boomerang Lake via the east dam in addition to the west dam. In **1993,** a small **(0.01** to **0.04 *Us;*1993)** seepage was observed at the base of the east dam in September and October. This seepage's pH averaged **5.28** at collection, and contained, on average, 118 mg/L zinc, 885 mg/L iron and **2204** mg/L sulphate.

The presence of this seepage confirms earlier suspicions that the tailings groundwater was leaking through the east dam, based on the water quality in piezometers M8 and **M44,** located below the east tailings dam towards Boomerang Lake shoreline (Map **2).** Zinc, iron and sulphate concentrations are as high as **192,** 156 and **2549** mg/L, respectively **(1988)** in these piezometers (Figure **23).**

Fig. 23: East Dam M8, M44, Seep Ann Avg
pH, [Zn],[Fe],[Acidity] and [Sulphate]



5.2 Water Balance and Contaminant Loadings

The monitoring data to date indicate that the Mill Pond oufflow, the Backfill Raise ditch, the tailings groundwater diversion ditch and seepages from the bases of the tailings dams all contain relatively high concentrations of iron, zinc, sulphate and acidity. The relative contributions of these contaminants to the deterioration of Boomerang Lake, or the contaminant loading, have to be derived from estimates of the hydrological conditions or the flow rates for the different contributing sources. These will be based on a water balance and are presented below.

5.2.1 Water Balance

Drainage areas and net annual precipitation volumes for the various basins and sub-basins comprising the South Bay site were based on the original hydrological evaluations of the site, calculated by R.O. van Everdingen in January, 1988. Net annual precipitation was calculated as the difference between mean annual precipitation (Ear Falls, Red Lake) and mean annual evapotranspiration (Hydrological Atlas of Canada) for the land areas of the various basins, and as the difference between mean annual precipitation and mean annual evaporation for the water bodies. The same estimates have to be used, since the hydrology for this area was not reassessed as was done for the tailings drainage basin as presented in Section 4.

The estimate indicates that a total of 343,603 m^3 of water leaves Boomerang Lake each year. The volume of Boomerang Lake is estimated at 1,000,000 m^3. At an annual input of 343,603 m^3, the volume of Boomerang Lake is exchanged every 2.9 years. Of this volume each year, over half of the volume is contributed by "clean" run-off from areas not affected by the mine site or tailings.

In Table 13 the base flow from the various contributions are presented in boxes, and flow directions are indicated with arrows.

Table **13:** Water Balance for Boomerang Lake Drainage Basin, 1992 - **1994.**

Tailings Seepage

1,200	m3/yr,	ROVE
0.04	=L/s	
0.01	L/s	12-Sep-93
0.04	L/s	09-Oct-93
0.004	L/s	31-Aug-94

Clean Run-off

192,648	m3/yr,	ROVE
6.1	=L/s	

Tailings Ditch/Pol Pond

8,176	m3/yr,	ROVE
0.3	=L/s	
0.04	L/s	12-Sep-93
0.08	L/s	09-Oct-93
0.027	**L/s**	**31-Aug-94**

Boomerang Lake Run-off (lake area only)

41,265 m3/yr, ROVE

OUTFLOW

343,603	m3/yr,	ROVE
10.9	**=L/s**	
61.2	L/s	12-Sep-93
9.6	L/s	09-Oct-93
11.7	**L/s**	**29-Aug-94**

IRC Ditch

0.052	**L/s**	**29-Aug-94**

Backfill Raise Ditch (BR2.5)

34,788	m3/yr,	ROVE
1.1	=L/s	
1.8	L/s	11-Apr-93
0.5/1	L/s	16-Jun-93
0.72	L/s	07-Sep-93
1.04	L/s	09-Oct-93
0.675	L/s	18-Jun-94
1.047	L/s	14-Jul-94
1.375	L/s	29-Aug-94

Mill Pond

65,526	m3/yr,	ROVE
2.1	=L/s	
0.06	L/s	16-Jul-92
0.13	L/s	07-Sep-93
1.2	L/s	12-Sep-93
0.07	L/s	09-Oct-93
0.075	L/s	18-Sun-94
0.139	L/s	14-Jul-94
0.32	L/s	29-Aug-94

Upper Dam

1.408	L/s	29-Aug-94

Warehouse Seep

0.27	L/s	09-Oct-93
0.163	L/s	18-Jun-94
0.350	L/s	13-Jul-94
0.32	**L/s**	**29-Aug-94**

Dave's Dam

0.004	L/s	09-Oct-93
1.64	L/s	29-Aug-94

The base flow based on drainage basin area and net precipitation can be compared to actual measurements made in more recent years for each drainage basin. Generally, the measured flow and the estimated flows are in good agreement for the oufflow from Boomerang Lake, for the tailings seepages, for the groundwater tailings/townsite diversion ditch and for the Backfill Raise diversion ditch.

The only sub-drainage basin which produces a problem is Mill Pond, which is considered to contribute the largest volume of water each year (65,526 m^3) according to the base flow. Flows estimated in the run-off areas (Dave's Dam and Upper dam, measured only 1994) are lower then the estimated base flow. It should be noted that, if the base flow from this drainage is taken and multiplied by the concentrations in Mill Pond, it would be the key contribution of contaminants to Boomerang Lake. The flows, given in the box, are those measured at the oufflow of Mill Pond since 1992. These flows are, on average, significant lower than the flow from the entire Mill Pond run-off area.

Such a difference between the estimated base flow and the limited number of measured flows is a prime example of difficulties encountered when loadings are calculated. Therefore, in the following section, estimated loadings from the Mill Pond sub-drainage basin, using Mill Pond concentrations of contaminants and the calculated base flow, represent the worst case scenario.

5.2.2 Contaminant Loadings

The calculated annual base flow of water draining from Mill Pond, the Backfill Raise ditch and the tailings groundwater diversion ditch (Table 13) were multiplied by the average concentrations of zinc, iron and sulphate in the respective flows.

In the case of the "fresh" water inflow, specific monitoring data is not available. Instead, the iron and sulphate concentrations used were each 0.1 mg/L, while for zinc, a concentration of 0.01 mg/L was used.

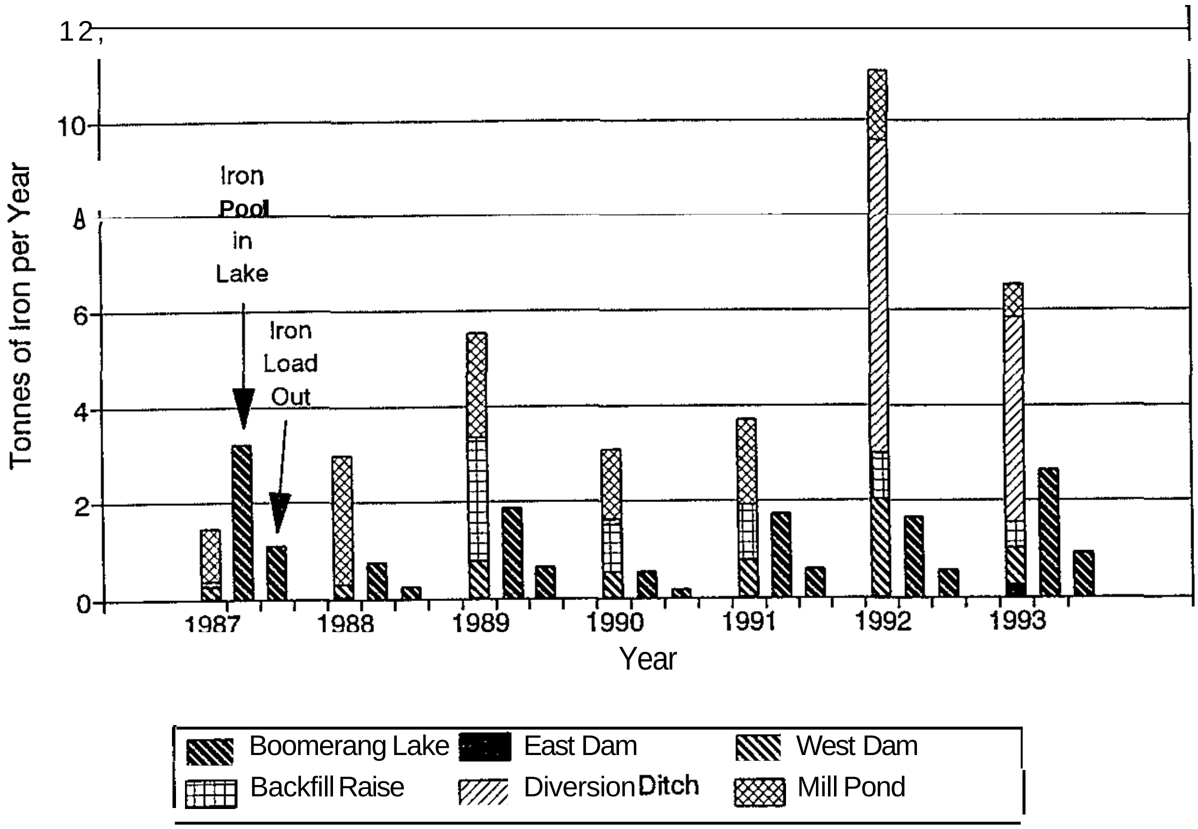
The seepage flows from the west and east tailings dams were collectively estimated at 1,200 m^3/yr (R.O. van Everdingen, 1988). Qualitative observations suggest that seepage flow from the west dam is much higher than from the east dam. Therefore, 900 m^3/yr was used as the seepage flow rate from the west dam, while 300 m^3/yr was used for seepage flow from the east dam during loading calculations.

It must be borne in mind that the subsequent loading estimates represent the maximum quantity of iron, zinc or sulphate, based on annual average concentrations, which could be entering Boomerang Lake from the various sub-drainage basins. These loading estimates do not, in any way, incorporate contaminant removal processes which may be occurring in the sub-drainage basins between the point of sampling and the point of entry into Boomerang Lake.

For instance, geochemical conditions may prevail in all sub-drainage basins which promote iron precipitation and sedimentation prior to entry to Boomerang Lake. Similarly, co-precipitation of zinc with ferric hydroxide, or adsorption of zinc by organic substrates, may, for instance, be occurring over the drainage path between Mill Pond ouflow and Boomerang Lake.

With this in mind, the results of these iron, zinc and sulphate loading calculations by year between 1987 and 1993 can be seen in Figures **24,** 25 and **26.** In these Figures, the loadings from the various sub-drainage basins are presented in the first stacked bar for that year. The second bar for each year represents the average amount of a contaminant, in tonnes, in Boomerang Lake during that year. The third bar represents the total amount of contaminant, in tonnes, which left the lake in the ouflow over the year.

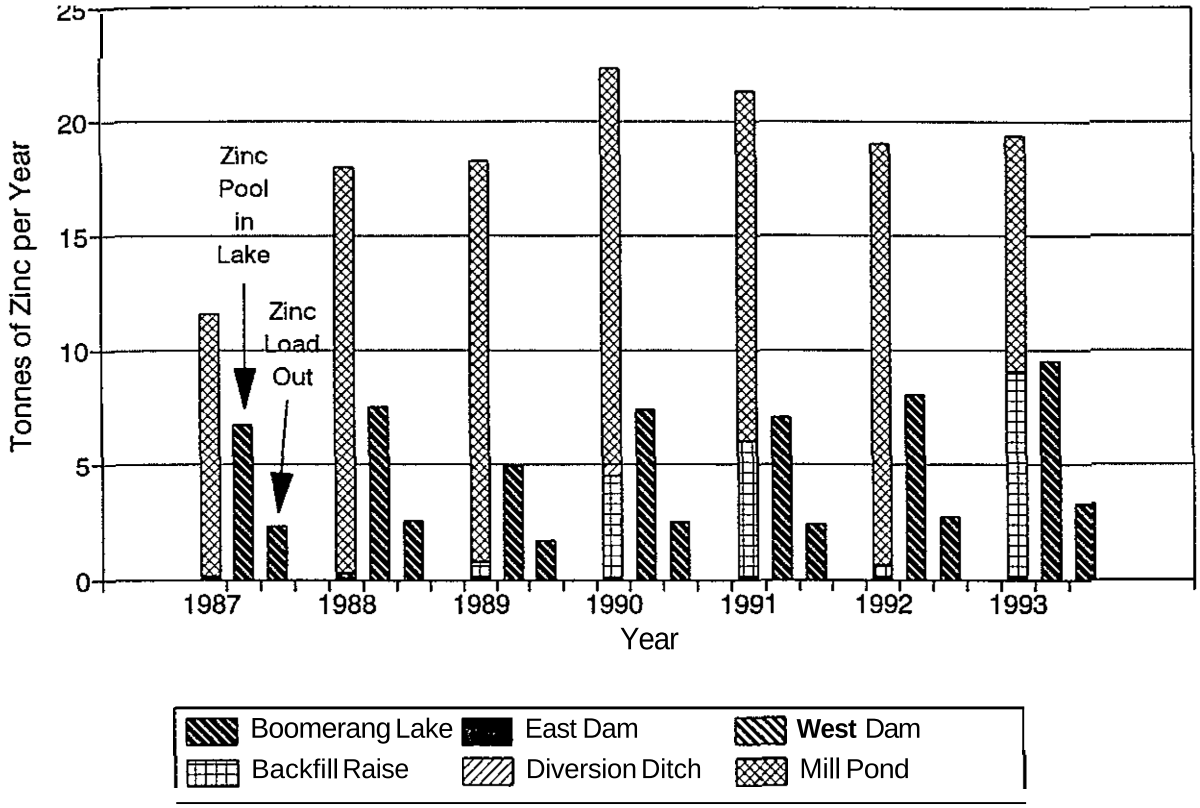
Fig.24: Iron Loadings in Boomerang Lake Drainage Basin, 1987 to 1993



<u>Iron:</u> For iron (Figure 24), it is clear that a consistently greater quantity is mobilized in the drainage basin each year (3 to 11 t/yr Fe), compared with the amount which leaves Boomerang Lake (1 t/yr or less). This indicates that iron is consistently removed in the sub-drainage basins and in Boomerang Lake prior to discharge. Ferrous iron oxidation, ferric iron precipitation and settling are, very likely, the processes responsible for the observed iron removal.

Mill Pond appears as a major contributor of iron in the years 1987 to 1991. However, higher iron concentrations measured in Backfill Raise ditch in 1989, 1990 and 1991 translated to relatively large contributions of iron from this area as well. In 1992 and 1993, the tailings groundwater diversion ditch was possibly the largest single contributor or iron to Boomerang Lake, based on the greatly elevated iron concentrations determined in samples from the ditch in these years.

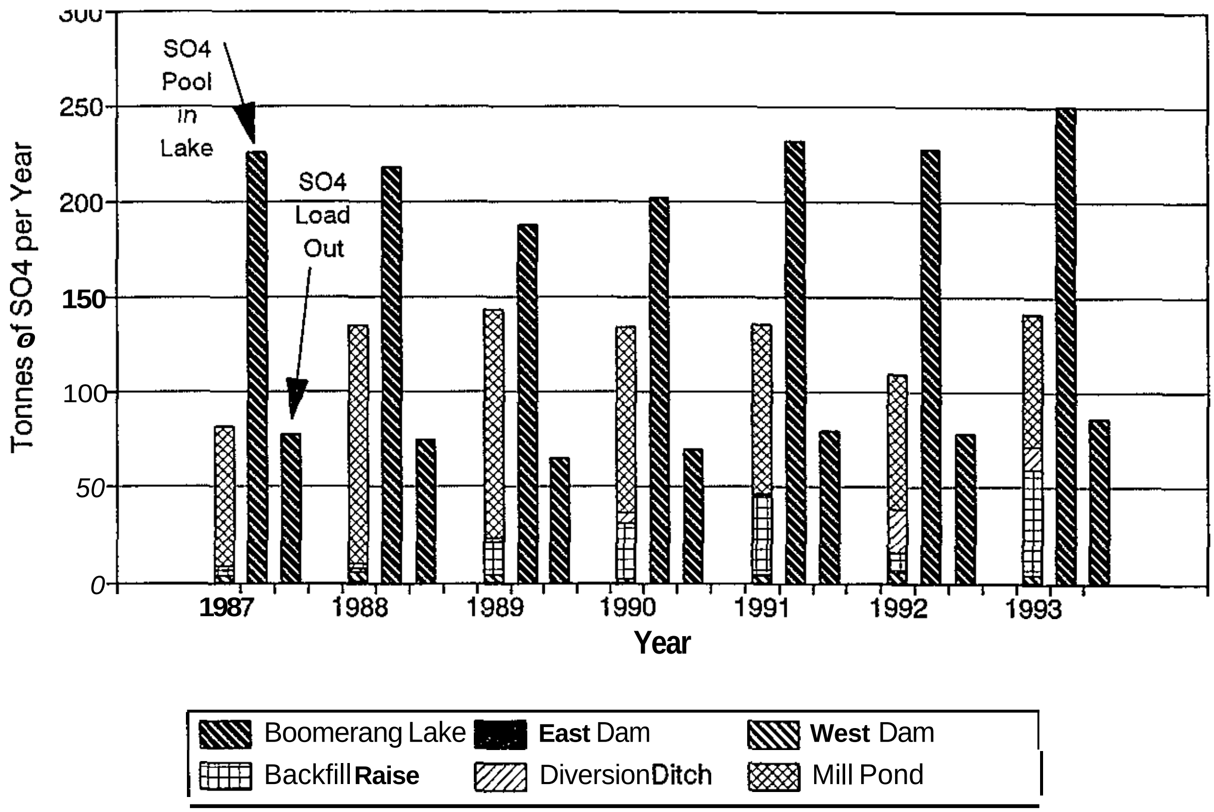
Fig.25: Zinc Loadings in Boomerang Lake
Drainage Basin, 1987 **to** 1993



<u>Zinc:</u> Between 1987 and 1993, 12 to 23 tonnes of zinc were mobilized each year in the various sub-drainage basins draining to Boomerang Lake (Figure **25).** Since far less zinc left Boomerang Lake in its ouflow (1.7 to 3.3 ffyr), effective zinc removal mechanisms must be operating in the sub-drainage basins and in Boomerang Lake at large.

In the years 1987 through 1989, the largest loading of zinc in the Boomerang Lake drainage basin was leaving Mill Pond (11 to 18 ffyr). However, in 1990, 1991 and 1993, comparable amounts of zinc were carried in Backfill Raise ditch drainage **(4** to 9 ffyr). Compared to Mill Pond and Backfill Raise, zinc loadings in the other sub-drainage basins were relatively minor. This, of course, would only be the case if indeed Mill Pond ouflow concentrations represent the total contribution to Boomerang Lake without any effects of the polishing capacity in the three retention dams and dilution from the cleaner side of the drainage.

Fig. 26: SO4 Loadings in Boomerang Lake Drainage Basin, 1987 to 1993



Sulphate: Between 1987 and 1993, an estimated 82 to 144 t sulphate were mobilized in sub-drainage basins draining to Boomerang Lake. In this same period, 65 to 86 tonnes of sulphate left Boomerang Lake in discharge water each year. Therefore, as observed for iron and zinc, some sulphate removal is likely occurring in the sub-drainage basins and Boomerang Lake prior to Boomerang Lake discharge.

Again, Mill Pond was consistently the greatest contributor of sulphate (Figure 26). Backfill Raise ditch typically contributed much less sulphate, with the exception of 1993, when it contributed a comparable amount to the Mill Pond ouflow contribution. The tailings groundwater diversion ditch and the tailings dams' seepages generally contributed very little sulphate, compared to Mill Pond and Backfill Raise.

5.2.3 Estimated Contaminant Removal

The estimated concentrations of contaminants, if no removal was taking place, can be calculated by using the iron, zinc and sulphate loadings within the Boomerang Lake sub-drainage basins, the contaminant concentrations in Boomerang Lake and the flow leaving Boomerang Lake. This estimated concentration can be calculated as follows:

$$[Contaminant]_{Year2} = \frac{Mass\ in\ Lake_{Year1} + Mass\ Input_{Year1} - Mass\ Disch.}{Volume\ of\ Lake}$$

The estimated iron, zinc and sulphate concentrations, according to this calculation, are given in Tables 14, 15 and 16 for the years 1988 to 1993. The measured and estimated contaminant concentrations can be then used to estimate contaminant removal for a particular year as follows:

$$Removal,\ in\ \% = \frac{[Estimated] - [Measured]}{[Estimated]} * 100$$

These estimates of iron, zinc and sulphate removal are also given in Tables 14, 15 and 16. It can be seen in these Tables that iron, zinc and sulphate are being consistently removed within the Boomerang Lake drainage basin. For iron, 69 % of the estimated iron loading mobilized in the sub-drainage basins is removed within the Boomerang Lake drainage basin and does not report to Boomerang Lake ouflow. Similarly, 67 % of the zinc remains within the drainage basin and does not leave in Boomerang Lake ouflow.

Year	Fe Input To Drainage Basin t/yr	Fe in Boomerang L. t	Fe Output Boomerang L. t/yr	Boomerang L. Measured [Fe], mg/L	Boomerang L Estimated [Fe], mg/L	Drainage Basin Estimated Fe Removal,%
87	1.54	3.23	1.11	3.23		
88	3.05	0.76	0.26	0.76	3.66	79.3%
89	5.63	1.89	0.65	1.89	3.55	46.9%
90	3.19	0.53	0.18	0.53	6.87	92.2%
91	3.79	1.73	0.59	1.73	3.54	51.2%
92	11.10	1.66	0.57	1.66	4.93	66.3%
93	6.61	2.66	0.91	2.66	12.19	78.2%
	4.99 t/yr avg	1.78 t avg	0.61 t/yr avg	1.78 mg/L avg		69.0%

Table 15: Zinc loadings to, and removal by Boomerang Lake Drainage Basin, 1987 - 1993.

Year	Zn Input To Drainage Basin t/yr	Zn in Boomerang L. t	Zn Output Boomerang L. t/yr	Boomerang L. Measured [Zn], mg/L	Boomerang L Estimated [Zn], mg/L	Drainage Basin Estimated Zn Removal,%
87	11.68	6.75	2.32	6.75		
88	18.10	7.49	2.57	7.49	16.11	53.5%
89	18.39	4.95	1.70	4.95	23.01	78.5%
90	22.40	7.40	2.54	7.40	21.64	65.8%
91	21.41	7.06	2.42	7.06	27.26	74.1%
92	19.14	8.04	2.76	8.04	26.04	69.1%
93	19.49	9.53	3.28	9.53	24.41	61.0%
	18.7 t/yr avg	7.32 t avg	2.51 t/yr avg	7.32 mg/L avg		67.0%

Table 16: Sulphate loadings to, and removal by Boomerang Lake Drainage Basin, 1987 - 1993.

Year	SO4 Input To Drainage Basin t/yr	Sulphate in Boomerang L. t	Sulphate Outpu Boomerang L. t/yr	Boomerang L. Measured [SO4], mg/L	Boomerang L Estimated [SO4], mg/L	Drainage Basin Estimated SO4 Removal,%
87	82	226	78	226		
88	136	218	75	218	231	5.5%
89	144	188	65	188	279	32.6%
90	136	202	69	202	268	24.6%
91	136	232	80	232	268	13.7%
92	110	228	78	228	288	21.0%
93	142	251	86	251	260	3.6%
	127 t/yr avg	220 t avg	76 t/yr avg	221 mg/L avg		16.8%

At the outset of this section, it was qualified that all of the iron, zinc and sulphate loadings estimated for each of the sub-drainage basins may not, in fact report directly to Boomerang Lake, but a fraction may be removed along the flow path between the sampling stations and the actual entry point to Boomerang Lake. From the estimated percent removal of iron and zinc, this remains a possibility.

The estimated sulphate removal *of* only **17 %** on average reveals **two** important points; first, since minimal sulphate removal can be expected at the observed low pHs in Boomerang Lake, the relatively low percent sulphate removal suggests that the sulphate, as well as iron and zinc mass balance estimates are relatively representative. Based on this confirmation on the approach taken for the loading estimation, it appears that iron and zinc are, in fact, retained in the drainage basin, while most of the estimated sulphate loading passes through the system and is discharged at Boomerang Lake outflow. These estimates are, indeed, in agreement with what would be expected from the removal processes presently operating in Boomerang Lake, biological polishing and co-precipitation of zinc with iron cycling. ARUM has not been implemented in the sediments, hence sulphate cannot be expected to be removed.

6.0 CONCLUSIONS

1) The water quality in Confederation Lake has to date not deteriorated. However, as demonstrated through intensive monitoring and the remedial actions taken in the last two years, the generation and transport of contaminants from a perched tailings deposit is extremely difficult to control.

2) Seepages which emerged from the surface of the mine/mill site, during the years 1991 and 1992 of extreme precipitation, and drained towards Confederation Lake have been curtailed.

3) The water in the undergrpund workings, which have been flooded since shutdown of the mine, is acidic and may be the origin of seepage at a depth of 6 m, moving through the sediments to Confederation Lake. Since the mine waters are still acidic, this contradicts the general belief that, through the flooding of underground working, acid generation is curtailed.

4) The reassessment of the hydrological conditions of the tailings site lead to the conclusion that the tailings deposit has to be viewed as a dynamic geochemical and hydrological system, prone to changes with time. Furthermore, the water balance indicated potential contamination of Mud Lake. This was confirmed in 1994.

5) Electromagnetic surveys have been carried out in areas where seepages might be suspected. The effects of the both diversion ditches, between the tailings and the townsite and the Backfill Raise diversion ditch, on the groundwater flow regime will be monitored by periodically repeating the EM surveys and comparing the results. This procedure allows for identifying any changes in discharge depth and movement of the seepages.

6) The water quality in Boomerang Lake has been deteriorating over the last few years with respect to pH, sulphate and acidity. Biological polishing and co-precipitation of zinc with iron hydroxide has reduced the rate of zinc increases. The concentrations are increasing due to changes in loading to Boomerang Lake. A summary of contaminant loadings to Boomerang Lake has been made. It is concluded that, in 1995, further applications of phosphate rock are required to improve the conditions of the lake. The planned treatment of Boomerang Lake in 1993 with the required phosphate material was not possible, as the preferred formulation of phosphate rock could not be bagged for distribution. Furthermore, the shipment of alternate material was delayed. Arrangements have been made to treat Boomerang Lake with the required phosphate rock in spring 1995.

7) In l991 and 1992, highly acidic water pooled on the tailings, due to the high precipitation during these years. As a result, the tailings pool run-off started to acidify Decant Pond. Remedial measures were immediately taken. The construction of a ARUM berm promoted microbial acid consumption and alkalinity generation along the beach. The tailings pool run-off area on the tailings was treated with phosphate rock. The zinc concentrations in the discharge from Decant Pond have improved. In 1994, zinc concentrations returned to 1 mg/L, from previous highs of 9 mg/L.

8) It is concluded that passive treatment methods remain a viable strategy for addressing contaminant removal at decommissioned sites.

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